Foreword

National
Oceanic and
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Administration

U.S.
DEPARTMENT
OF
COMMERCE

NOAA Fisheries Service
Northeast Cooperative Research Partners Program

The National Marine Fisheries Service (NOAA Fisheries Service), Northeast Cooperative Research Partners Program (NCRPP) was initiated in 1999. The goals of this program are to enhance the data upon which fishery management decisions are made as well as to improve communication and collaboration among commercial fishery participants, scientists and fishery managers. NOAA Fisheries Service works in close collaboration with the New England Fishery Management Council's Research Steering Committee to set research priorities to meet management information needs.

Fishery management is, by nature, a multiple year endeavor which requires a time series of fishery dependent and independent information. Additionally, there are needs for immediate short-term biological, oceanographic, social, economic and habitat information to help resolve fishery management issues. Thus, the program established two avenues to pursue cooperative research through longer and short-term projects. First, short-term research projects are funded annually through competitive contracts. Second, three longer-term collaborative research projects were developed. These projects include: 1) a pilot study fleet (fishery dependent data); 2) a pilot industry based survey (fishery independent data); and 3) groundfish tagging (stock structure, movements and mixing, and biological data).

> First, a number of short-term research projects have been developed to work primarily on commercial fishing gear modifications, improve selectivity of catch on directed species, reduce bycatch, and study habitat reactions to mobile and fixed fishing gear.
>
> Second, two cooperative research fleets have been established to collect detailed fishery dependent and independent information from commercial fishing vessels. The original concept, developed by the Canadians, referred to these as "sentinel fleets". In the New England groundfish setting it is more appropriate to consider two industry research fleets. A pilot industry-based survey fleet (fishery independent) and a pilot commercial study fleet (fishery dependent) have been developed.
>
> Additionally, extensive tagging programs are being conducted on a number of groundfish species to collect information on migrations and movements of fish, identify localized or subregional stocks, and collect biological and demographic information on these species.

For further information on the Cooperative Research Partners Programs please contact:

National Marine Fisheries Service (NOAA Fisheries Service)
Northeast Cooperative Research Partners Program

(978) 281-9276 – Northeast Regional Office of Cooperative Research
(401) 782-3323 – Northeast Fisheries Science Center, Cooperative Research Office, Narragansett Laboratory

www.nero.noaa.gov/StateFedOff/coopresearch/

THE EFFECTS OF MESH SIZE AND SHAPE ON SIZE SELECTIVITY IN THE MULTISPECIES FISHERY

Final Report Submitted to
National Marine Fisheries Service
Cooperative Research Program

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THE EFFECTS OF MESH SIZE AND SHAPE ON SIZE SELECTIVITY IN THE MULTISPECIES FISHERY

EXECUTIVE SUMMARY

The goal of this project was to test the escapement of cod, yellowtail flounder, and other species included in the Multispecies Plan through diamond knotted mesh in the codend as control, and square and hexagonal ultracross knotless mesh as treatments. We were especially interested in testing the release properties of ultracross knotless netting, especially in hexagon shape. The project also tested escapement properties of grates installed before the codend. A horizontally orientated grate with 3 inch bar spacings and a vertically orientated grate with 4 inch bar spacings were tested to determine if they can be used to separate flatfish from gadoids

To determine the selectivity of different mesh shapes and materials in the codend, we compared the total weight and size composition of commercial species in the catch between the following cod-ends by trawling two cod-ends simultaneously in a trouser-trawl arrangement:

a) 6 inch diamond polyethylene vs 6 inch diamond polyethylene (control)
b) 6.5 inch square ultracross mesh vs. 6 inch diamond polyethylene.
c) 6 inch hexagon ultracross mesh vs. 6 inch diamond polyethylene.
d) 6.5 inch hexagon ultracross mesh vs. 6 inch diamond polyethylene.

To determine the effect of a grate on the size selectivity of flat fish and of gadoids, we installed the grate on a 3 inch diamond mesh codend and placed a retaining bag, also made of 3 inch diamond mesh, on top of the grate, then we compared the species and size composition of the catch from the codend and the retaining bag. The codend collected fish that passed through the grate (control codend) and the retaining bag collected fish diverted by the grate (experimental or cover codend). Grates with 4 inch vertical bars and 3 inch horizontal bars were tested.

The data were collected during two consecutive trips in late May and early June, 2001, totaling 43 hauls in 10 days at sea on Stellwagen Bank. The first four hauls were performed with two identical codends, made of 6 inch diamond meshes, which is the standard mesh used in this fishery. These control hauls were used to test for potential biases of the trouser trawl setup.

An A-B-B-A pattern of alternating codends was followed throughout the trip, whether dealing with a control haul (two identical 6 inch diamond codends) or an experimental haul (one control 6 inch diamond mesh codend and one experimental codend). The codends equipped with grates operated in a different manner: a grate measuring 54 inches by 40 inches, with horizontal bars every 3 inches (or with vertical bars every 4 inches), was attached obliquely to the entrance of the codend. At the top of the grate, where fish too large to pass through the bars would tend to be forced upwards by water pressure, was a small window cut into the codend similar to the arrangement of the widely used Nordmore grate. A 3 inch diamond mesh retaining bag or cover was then attached to this window to retain fish too large to pass through the bars. Fish passing through the bars were captured in the 3 inch mesh codend behind the grate.

The first 7 hauls (4 of which were control and the remaining 3 testing one standard 6 inch diamond mesh codend against a 6.5 inch square mesh codend) appeared to the operators on deck to show a potential side bias: the codend on the port side always appeared fuller than the other. Videotape taken on the first day indicated that cod were avoiding the darker mesh (ultracross). In order to correct for this, the crew modified the length of the split, making the legs of the trouser trawl (before the codend) longer by approximately 20 feet in the control trawls and 16 feet in the trawls collecting data on comparison of the control with the experimental gear. Both the control hauls and the experimental hauls testing the 6.5 inch square mesh codend, were repeated with the longer split.

After each tow, observers recorded the total weight and individual length for each of the 11 multispecies from each codend. All data were collected following NMFS protocols and logged on NMFS approved data forms.

The data analysis to test retention concentrated mainly on comparing length frequency distributions (LFD) between the codends and calculating selectivity curves primarily for the abundant cod and yellowtail flounder species but in some instances for some of the more abundant of the other commercially important species. The non-parametric Kolmogorov-Smirnoff Two-Sample (KS-2) test was used to test for differences between the LFDs.

For two major species, cod and yellowtail flounder, KS-2 tests showed significant differences in the LFDs for the control, where both codends used the same 6 inch - diamond mesh netting. This confirmed the observations of a potential side bias observed by the operators on deck during fishing operations. The modifications of adding a split or extension before the codends appear to have corrected this bias, because no significant differences surfaced for the control-L treatment.

KS-2 tests showed few significant differences between experimental and control codend for any of the treatments. Cod and haddock retained by the experimental codends made of 6.5 inch sq mesh, however, had significantly different LFDs from their control codends, both before and after the modifications to the length of the split. However, since it is impossible to separate the effect of the side bias from that of the experimental treatment, only the results obtained after the modification to the length of the split are considered valid.

In the case of the grates, significant differences between fish retained in the codend and fish caught in the cover were expected, in terms of LFDs, since the purpose of the grates was to let small fish escape from the codend. It is interesting to note that this was not true for most of the species. The lack of significance may have been due to the generally small size or small number of that species caught but may also indicate that the selected bar spacing was not appropriate for selecting the species in question.

Selectivity curves for all experimental treatments were calculated using the SELECT Method, as appropriate to analyze paired gear selectivity data. Given the presence of replicate hauls for the same gear, hauls were combined, then the total catch was estimated and the data pooled. The selectivity curve resulting from a combined hauls analysis gives the mean selection curve for the gear tested.

This study has confirmed that it is easier for roundfish, like cod and haddock, to escape from square meshes than from diamond meshes, since the LFDs of cod and haddock in a 6.5 sq codend were significantly different than in the control codend: fewer but bigger fish were retained in a 6.5 inch square mesh codend than in the 6 inch diamond mesh codend. Hexagonal knotless meshes potentially present an interesting intermediate shape between square and diamond shaped meshes. However, during the present study, it appears the codends made of hexagonal meshes were hung in a manner that allowed them to take a shape very similar to diamond mesh netting. The 6.5 inch hexagon stretched mesh averaged 5.9 inches and the 6 inch hexagon stretched mesh averaged 5.5 inches. The 6 inch diamond stretch mesh averaged 6 inches and the 6.5 inch square averaged 6.5 inches. Therefore, in this case, it is possible that the 6.5 inch hexagonal mesh codends appeared very similar to the 6 inch diamond codends, while the 6 inch hexagonal mesh codend may have appeared like a 5.5 inch diamond mesh codend. This would explain the lack of significant results when comparing the control diamond codend and the experimental hexagonal codends in terms of LFDs. This is an area of research that requires further examination.

The other main goal of the study was to explore escapement by species and size of individuals through rigid grates. In particular, this study aimed at determining whether grates can be used to separate flatfish from roundfish. The opening above the grates were covered with a small mesh cover, so that it would be possible to account for all fish that were excluded by the grate. The horizontal grate, with bars 3 inches apart, was effective at diverting the larger yellowtail flounder, while having no detectable effect on cod and haddock. More work needs to be done to confirm these results, but it appears that such a grate could be used to target selectively larger flatfish while releasing roundfish and smaller flatfish. The vertical grate, with bars 4 inches apart, was effective at diverting both larger yellowtail and larger cod. So, while this type of grate was not effective at species separation, it did show potential for size separation.

The retention rates of the various experimental codends used in the trouser trawl were quantified by their respective selectivity curve. In the case of cod and haddock, the 6 inch diamond codend would release approximately 50% of the MLS fish, as the L50 is very close to MLS. Although this means that most of the marketable catch is retained, it also means that certain portion of the catch will be made of sub legal fish that will need to be discarded at sea. To reduce discard rates of cod and haddock, the selectivity study confirmed that a 6.5 inch square mesh codend is more effective, placing the 50% retention point at 60 cm for cod and at 56 cm for haddock, considerably above MLS.

In the case of yellowtail flounder, results can be interpreted using the same logic: while the 6.5 inch square mesh codend had the L50 closest to the MLS, the 6 inch diamond would be more effective at reducing discard rates of sub legal fish. It is interesting to note that in the case of yellowtail flounder, the 6 inch hexagonal mesh codend performed virtually the same as the 6 inch diamond mesh codend, confirming that their respective hanging ratios made them similar in appearance and function. However, this does not appear to be true to the same degree for cod.

Overall, the program of research has produced a number of significant findings. Clear differences are evident in the selective efficiency of different mesh types and configurations. Some of these differences are self-evident. That is, diamond meshes in general are more effective at releasing flatfish while square and hexagonal meshes are more effective at releasing roundfish such as cod and haddock. However, many of the experimental comparisons were not significantly different for a number of species. It is not immediately obvious why this is the case, but it may indicate either that there is less difference between say square mesh and diamond mesh, than would be expected or more likely that between haul variability is masking the true nature of the effect. Increased sample size would help elucidate such differences.

We found hexagonal mesh to perform less well than anticipated. Hanging aspect or ratio is critical for correct functioning of hexagonal mesh. Meshes can take a number of shapes, including elongate diamond, depending on how the meshes are attached to the meshes of the main body of the net. It is likely that the meshes during this study adopted a diamond shape and this may indeed account for the surprising performance of the hexagonal mesh.

It is clear that hexagonal mesh is effective to a certain degree in helping to reduce bycatch, however more research is needed both in terms of hanging ratio and appropriate mesh size before introduction into multi-species fisheries.

The selection grates investigated in this study indicated the potential effectiveness of grates as size sorting devices. However, grates are generally less effective as species sorting devices except where there are either major differences in behavior between target and non-target species, or where there are major differences in body shape between target and non-target species for example shrimp and fish. The results presented here suggest that rigid grates may be used effectively as size sorting devices (and hence bycatch reduction tools) but overall the results are inconclusive and much more work is required.

THE EFFECTS OF MESH SIZE AND SHAPE ON SIZE SELECTIVITY IN THE MULTISPECIES FISHERY

INTRODUCTION

At the time of the study, the New England Fisheries Management Council's regulations in the Northeast Multispecies Fishery Management Plan (Multispecies Plan), required the use of either 6 inch diamond mesh or 6.5 inch square mesh codends. Current regulations require 6 inch mesh of either configuration. There is insufficient scientific data, however, on comparative selectivity of the two mesh sizes and shapes. Square mesh generally retains more flatfish (yellowtail flounder, dabs, winter flounder, and other flounders), while allowing more roundfish (cod, haddock, hake and pollock) to escape, and diamond mesh generally retains more roundfish while allowing more flatfish to escape. As a rule of thumb, therefore, fishermen use square mesh when the predominant or targeted species are yellowtail and other flounders, and they use diamond mesh when the predominant or targeted species are gadoids and other roundfish.

Management plans also use mesh shape as a strategy to reduce fishing mortality of less abundant fish stocks while landing more abundant species. In the Gulf of Maine, for example, where the Multispecies Plan calls for low possession limits of cod, discards of cod are often common while targeting flatfish. Mesh that allows the escapement of cod would conserve that fishery both in terms of the cod stock and of fishing families, by allowing them to target other species.

Recently, a material known as ultracross knotless netting became available for commercial fishing. It is manufactured by a patented process that maximizes the material's strength, by eliminating knots, balancing the braids and running continuous filaments through the netting. The material used is high tenacity polyethylene that does not elongate under load. Escape of small fish is easier using ultracross because the opening of the mesh is not restricted by knots, thereby allowing a slightly larger opening than in a conventional mesh. Furthermore, knotless ultracross netting may minimize the damage to those fish that escape. Ultracross netting also improves water flow through the net because the opening is wider thereby reducing the drag.

Ultracross netting has not been used commercially because construction was more difficult and higher cost than other materials, and it was more difficult to repair. Now it is available in very strong material, easily repairable, and available in square, diamond and hexagon webbing. Despite these recent advances however, ultracross netting continues to be expensive.

Hexagon mesh generally seems an improvement over square and diamond mesh for escapement of cod and other gadoids because it better conforms to their shape and diamond mesh seems a better shape for escapement of flounders. If a codend built of hexagon mesh proves to have a selectivity similar to square mesh for flat fish (soles and flounders) while affording more cod and other gadoids to escape, it may be used as a tool to rebuild cod stocks, by allowing fishermen to catch flat fish with fewer cod discards.

Grates with parallel bars can also be used to select individuals for exclusion or retention. Grates have been used in several fisheries for selection between different species, excluding halibut from otter trawls in the Pacific flounder fishery, for example. Grates could potentially prove useful in the Northeast Multispecies fishery to select species by their shape and individuals by size. If this is the case, their use may also help to eliminate discards of species with low possession limits and juveniles in order to help rebuild these stocks.

This project tested hypotheses about escapement by species and size of individual fish through different size and shape of webbing in the codend. This project also tested selectivity through grates of 3 inch bars horizontally orientated and a 4 inch bars vertically orientated to determine if they can be used to separate flatfish from gadoids.

This report is organized into the following sections: Review of Previous Studies, Experimental Design, Sea Trials & Data Collection, Results, and Discussion.

REVIEW OF PREVIOUS STUDIES

Most previous experiments using ultracross netting to test the escapement and of gadoids and flatfish from different size and shape cod ends were performed in the Baltic Sea, in the Pacific off the coast of Washington or Alaska, or in the Northwest Atlantic.

Dr. Petri Suuronen, Research Director for the Finnish Game and Fisheries Institute, and several colleagues from other countries with fishing interests in the Baltic Sea have concluded several studies of the effects of mesh size, shape, and escape windows in otter trawls on retention and selectivity of cod and herring in the Baltic Sea and Gulf of Finland. In an earlier study, he and his colleagues tested retention and escape from diamond and hexagonal mesh in the codend in mid-water otter trawls (Suuronen, P., Millar R. & Jarvik, A. 1991). Using commercial vessels, they conducted fishing trials using trouser trawls with small mesh control codend to test selectivity of 32 mm diamond mesh and 33 mm hexagon mesh. The tests ran into problems with bias in the catch between the two sides and high variability between individual hauls. Comparing the pooled data from the diamond mesh with the pooled data from the hexagonal mesh, they concluded that both gears caught large numbers of small herring, but the 33 mm hexagonal net caught more small fish than the 32 mm diamond mesh.

In a more recent and more complete study, Dr. Suuronen and colleagues investigated selectivity of square ultracross and diamond knotted mesh in the codend and various sized escape windows made from square ultracross netting (Suuronen, P., 2000). From June, 1998 to March, 1999, BACOMA, an EU funded cooperative project with the Institute of Marine Research, Sweden, the Danish Institute for Fisheries Technology and Aquaculture, ConStat, Denmark and the Finnish Game and Fisheries Research Institute conducted experiments in the Baltic Sea using commercial fishing vessels (both stern trawlers and side trawlers) ranging from 26 to 210 GRT. The experiments utilized two codends, one with a cover and one without, towed simultaneously in a twin trawl rig with the goal of estimating selectivity of the various gears and survival of escaped fish. Using the data from their sea trials, they used models to assess the impact of increased mesh size on fish populations and commercial catches.

Their results were quite extensive:

1. Codend covers reduced the size of the catch but did not affect the size frequency distribution with relation to uncovered codends.
2. A panel of square ultracross netting (ranging from 110 mm to 135 mm) on the top of the extension piece just before the codend increased escape of juvenile cod. Catch of cod under the minimum landing size (MLS) was reduced by 53%.
3. Increasing the size of the square mesh window area in the aft-most part of the codend, substantially improved the escape of smaller cod. The knotless Ultra-Cross netting met the requirement for a strong material with stable mesh configuration that is a necessity for a square mesh window employed in high-stress areas such as the aft portions of the codend.
4. The mesh size trials indicated that escape of small cod is significantly higher when a square mesh top panel window codend is compared with a conventional diamond mesh codend of the corresponding mesh size. Escape of smaller cod decreased significantly with a larger catch for standard diamond mesh codend but not in the square window codend. These characteristics support the use of a square mesh window codend in the future fisheries for Baltic cod.
5. Vessel size and type (stern vs side trawlers) affected selectivity. Side trawlers allowed more escape of juveniles than stern trawlers, because side trawls are hauled back under less tension, allowing juveniles more time to escape.
6. Towing speed affected the range of selectivity, faster tows reduced the range of selectivity for different mesh size, but towing speed did not affect the average size at the fish that the net captured.

7. Mortality was low for escapees (less than 3%) and varied indirectly with fish size. Water temperature had the largest effect (colder water reduced mortality). Injury, on the other hand, was positively associated with fish size. Escape through the diamond mesh caused more injury than escape through the square mesh escape panels. Differences in mortality were quite small, however, relative to the difference in selectivity among different mesh sizes and escape windows
8. Increase in mesh size would increase long term spawning biomass and landings of Baltic cod.
9. The short-term losses due to increased mesh size regulations would be less when the changes in regulations were initiated with large recruiting class.

Dr. Suuronen and his colleagues also summarized the practices and effects of technical measures in fishery management, including gear modification (codend mesh size and shape, escape windows and grids), and time and area closures in a subsequent publication (Suuronen, P., 2001).

There have been a number of experiments off the West Coast of the U.S. and Alaska testing selectivity and discards by type, shape, and size of mesh in the codend. John Wallace et al. 1996, tested differences in performance between various sized knotted diamond shape netting and ultracross knotless square netting at various locations off Northern California, Oregon, and Washington (Wallace et al, 1996). Using alternative tows from commercial fishing vessels, they compared the total numbers and weights of marketable-sized fish, of under-sized fish and of gilled fish for each of the main commercial Pacific groundfish species for the different gears. Their goal was to select the best gear in terms of minimizing discard rate for inner and outer near shore. They recommended using a minimum mesh size of 114 mm (4.5 inches) for all nearshore fisheries because the discard rate was significantly higher for smaller mesh sizes. Once again, in terms of the discard rate, square mesh worked better in the outer nearshore mesh due to the higher relative abundance of cod and rockfish, while diamond mesh allowed more escapement for the inner nearshore fishery due to the relative abundance of flatfish.

In 1988 and 1990, Perez-Comas and his colleagues compared retention of immature Pacific flounders and rockfish from different size and shape codend meshes using alternate tows from commercial fishing vessels (Perez-Comas, et al, 1998). They used 76 mm diamond knotted mesh as the standard and knotted diamond meshes (114 mm, 127 mm, and 140 mm) and knotless square meshes (114 mm and 127 mm) as treatments. Retention of small fish decreased with mesh size for both classes of species and both mesh shapes, especially for square mesh. The smaller square mesh (114 mm) retained more small fish than the other meshes, including the control 114 mm diamond. This may have been due to the species mix. For flounders, square meshes were less selective than diamond meshes, but this pattern of selectivity was less apparent for rockfish. There was a tendency for retention of more very small and very large fish, which may have been caused by large catches clogging the mesh.

In 1994, Erickson and his colleagues (essentially the same team as from the previous study) concluded that size of the catch reduced the selectivity of large square and diamond mesh in the walleye pollock fishery from tests in the Bering Sea (Erickson et al, 1996). Using alternate tows from commercial fishing vessels, they tested escapement from different size and shape meshes in the codend, using diamond knotted mesh (double layer, 85 mm), as the control gear and single layer knotted diamond mesh (88 mm), knotless ultracross diamond mesh (113 mm), and escape panels of ultracross square mesh (95 mm and 108 mm) as experimental gear. For large catches (> 40 mt), retention of undersized pollock was not significantly different between the control and experimental codends. For smaller catches, all experimental codend retained a significantly lower portion of undersized fish than the smaller mesh control codend.

In 1997 and 1998, Erickson and his colleagues conducted experiments using commercial fishing vessels to test for escapement of walleye pollock through escape panels on top of the extension piece and on the top of the codend (Erickson et al, 1999). They also estimated mortality of fish that escaped by collecting and towing them to cages anchored at sea, where they were checked by divers.

Escape panels, located on the top of the extension piece before the codend, were constructed of knotless square meshes (93 mm and 77 mm) and 116 mm knotted diamond mesh. Videotaping showed that the escape panel cover, which guided escapees into a collection cage, often went slack, collapsing onto the mesh. The researchers attached kites and floats to spread the cover, which remained some distance away from the trawl meshes following this adjustment. Videotaping also showed that 93 mm square meshes allowed many pollock smaller than 30 cm to escape through the meshes of the codend and the extension.

Another vessel caught pollock in a seine and transferred them to cages as a control to compare their mortality with the fish that escaped through the codend and escape panels.

Many pollock that escaped showed scrapes and bruises. Most mortality was early, within the first 4 days. Fourteen-day mortality was 46% to 84 % from codend and 47% to 64% from escape panels. Some of this mortality may have been caused by keeping the escaped fish in cages. Statistical tests showed no significant differences between mortality for those that escaped through the escape panel and those that escaped through the codend. The differences in mortality between the control and experimental gear, however, were significant. Seined fish had lower mortality. There was an inverse significant relationship between size and mortality for the escaped fish, although larger fish showed more bruises than smaller fish (Bublitz et al, 1999).

In 1998 and 1999, Glass and his colleagues conducted experiments on Stellwagen Bank and in the Gulf of Maine to test escapement and selectivity through different size and shape mesh in codends using the trouser trawl arrangement (Glass et al., 2000). They used 6 inch diamond mesh as control and composite codends (made from diamond and square mesh) and 6 inch and larger ultracross knotless square mesh as experimental codends. In general, experimental codends had lower catches than their respective control codends both in terms of weight and of numbers for cod and flatfish. However, for cod these differences were never significant, but most comparisons between experimental codends and control were significantly different for the various species of flatfish. The composite codend made of 6.5 inch square mesh on top and 6.5 inch diamond mesh on the bottom caught significantly fewer but larger yellowtail and winter flounder than its control, and the 7 inch square mesh codend caught significantly fewer but larger yellowtail flounder than its control, but did not prove effective at releasing grey sole and other large flatfish. Experimental codends made entirely of square mesh generally retained considerably fewer fish than composite codends.

Grates have been widely tested and included in regulations to release fish and turtles from small mesh shrimp trawls. Fewer experiments have focused on selecting different species and different sized individuals from otter trawls.

In 1998, the Groundfish Forum, an industry trade association, and the National Marine Fishery Service conducted experiments to test a circular, rigid grate with 6 inch square openings over its entire surface that would direct halibut out of the trawl but allow other flatfish to pass through to the codend. Two commercial fishing vessels were equipped with two trawls, one with the grate and the other without it. Each vessel alternated experimental and control gears to create pairs of tows (blocks) conducted under similar conditions. Every 5 tows the grates were transferred to the other trawl on the same vessel in order to offset any bias between the nets. Combining the data from both vessels, the excluder retained only 6% of the halibut, while keeping 62% of the other deepwater flatfish species (Gauvin & Rose, 2000).

In 1992 and 1993, the Department of Fisheries and Oceans, Government of Canada contracted with Fishery Products International (FPI) to conduct sea trials to test grates with various size vertical and horizontal bars (DFO). Commercial fishing vessels were equipped with trawls with grates installed just before the codend with covers behind both the grates and the codend to determine escape through both. The goal was to test the effect of the grates on the escape of cod around the grates.

The sea trials resulted in large scale escapement of cod but also allowed escapement of flatfish, especially for grates with horizontal bars. Rigid grates of 127mm (5 inches) or 152mm (6 inches) vertical bar spacings successfully separated large cod from flatfish. The effectiveness of the grates was reduced, however, when large amounts of small cod were present in the trawl. After the experiments, FPI fitted each of its 27 vessels with 140 mm rigid grates that were used when fishing in areas with traditionally high levels of cod by-catch, which resulted in sufficient reduction in cod bycatch. This allowed the company to catch a larger portion of its flatfish quota.

It is clear that ultracross and hexagonal netting have received considerable attention and interest around the world. It is also clear, despite certain successes, that more investigation of the properties and merits of these new twine types is required. This is particularly true for the waters of the Northwest Atlantic and is the basis for the report presented here.

EXPERIMENTAL DESIGN

The goal of this project was to test the escapement of cod, yellowtail flounder, and other species included in the Multispecies Plan through diamond knotted mesh in the codend as control, and square and hexagonal ultracross knotless mesh as treatments. We were especially interested in testing the release properties of ultracross knotless netting, especially in hexagon shape. The project also tested escapement properties of grates installed before the codend. A horizontally orientated grate with 3 inch bar spacings and a vertically orientated grate with 4 inch bar spacings were tested to determine if they can be used to separate flatfish from gadoids

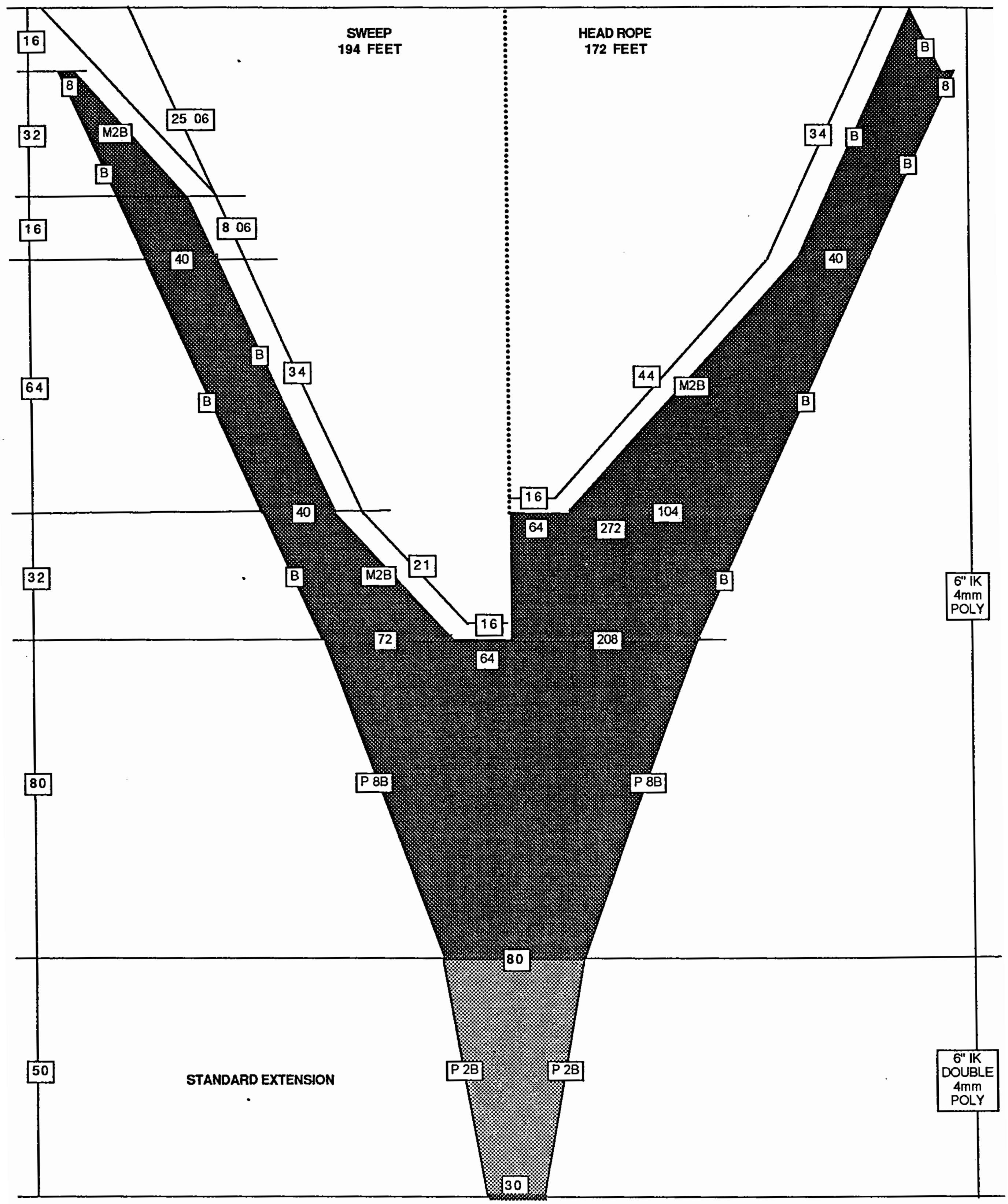
To determine the selectivity of different mesh shapes and materials in the codend, we compared the total weight and size composition of commercial species in the catch between the following cod-ends by trawling two cod-ends simultaneously in a trouser-trawl arrangement (Glass et al, 2000):

e) 6 inch diamond polyethylene vs 6 inch diamond polyethylene (control)
f) 6.5 inch square ultracross mesh vs. 6 inch diamond polyethylene.
g) 6 inch hexagon ultracross mesh vs. 6 inch diamond polyethylene.
h) 6.5 inch hexagon ultracross mesh vs. 6 inch diamond polyethylene.

The two codends were attached to the back of the net in a trouser-like arrangement (Robertson et al, 1990). The codends were swapped from side to side between tows following an A-B-B-A pattern to avoid potential side bias. Hence, the codend fishing on the port side in the "A" tow would fish on the starboard side on the subsequent "B" tow. Further, the fishing direction of A-B tows and B-A tows were generally 180 degrees from each other.

To determine the effect of a grate on the size selectivity of flat fish and of gadoids, we installed the grate on a 3 inch diamond mesh codend and placed a retaining bag, also made of 3 inch diamond mesh, on top of the grate, then we compared the species and size composition of the catch from the codend and the retaining bag. The codend collected fish that passed through the grate (control codend) and the retaining bag

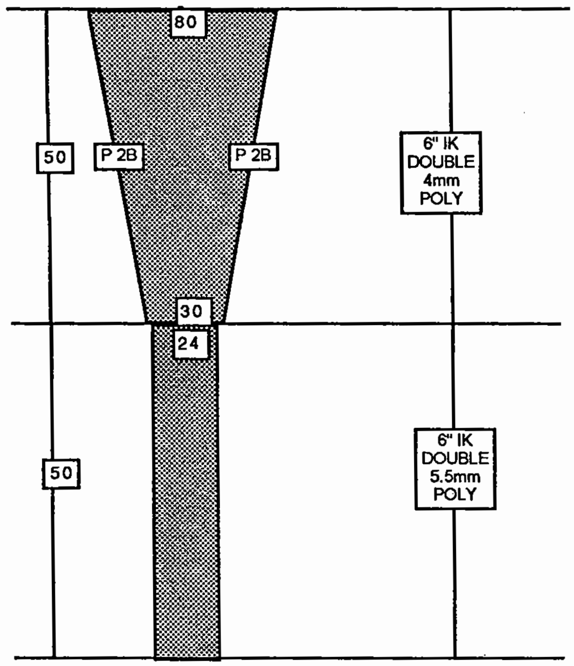
DIAGRAM 1. RITA SOPHIA OTTER TRAWL



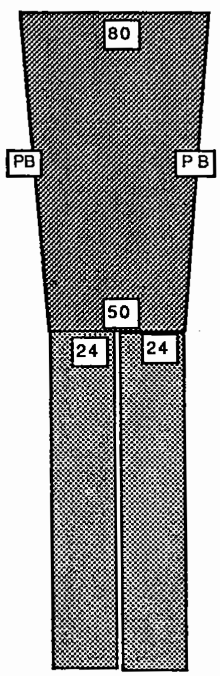
1999 - 2000

DIAGRAM 2. EXTENSION WITH ONE ANDTWO CODENDS

STANDARD EXTENSION/CODEND
ARRANGEMENT



EXTENSION
WITH 2 CODENDS



EXTENSION WITH 2 CODENDS
AFTER TOW # 7
(EXTENDED SPLIT 31 MESHES)

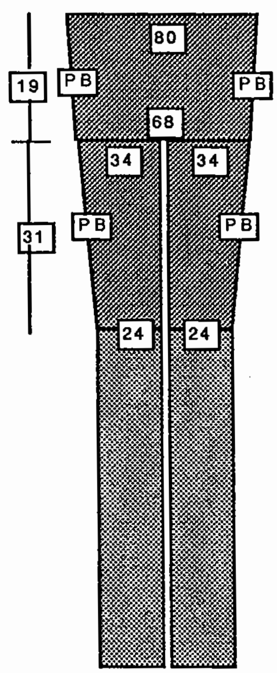
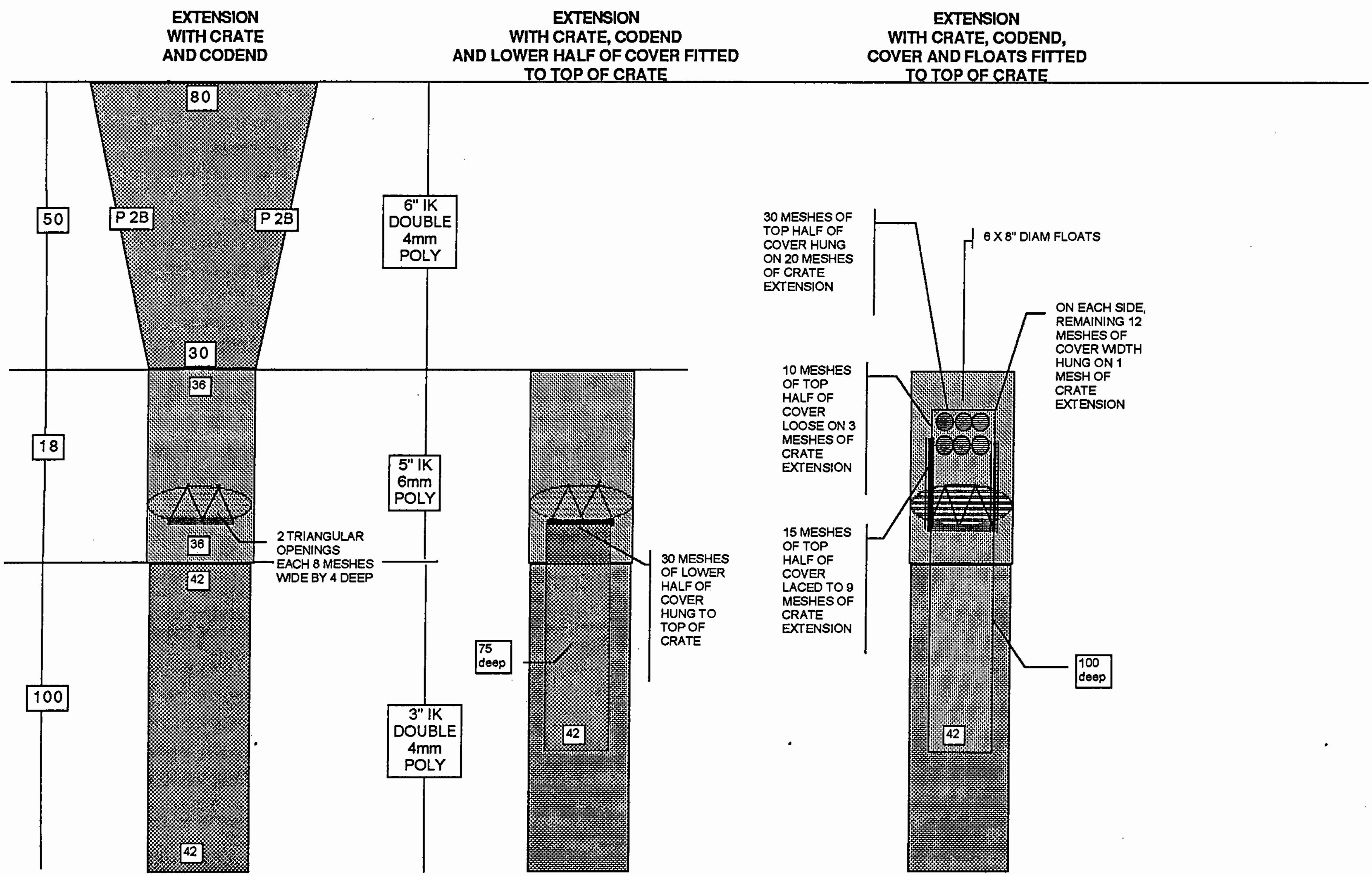


DIAGRAM 3. EXTENSION, CRATE AND 2 CODENDS



collected fish diverted by the grate (experimental or cover codend). Grates with 4 inch vertical bars and 3 inch horizontal bars were tested.

These experiments targeted the multi-species complex, specifically gadoids (cod and haddock) and flatfish (yellowtail and blackback founders). We conducted these experiments during late May and early June of 2001 on Stellwagen Bank. (See Appendix A. Fishing Log.)

After each tow, observers recorded the total weight and individual length for each of the 11 multispecies from each codend. All data were collected following NMFS protocols and logged on NMFS approved data forms. Data will be made available to NMFS in electronic format and paper format as requested.

The optimal codend should be selective, i.e. retain only the desirable fish, generally defined as the large individuals of the target species. Such a codend would interact with the fish population sampled in each tow and select towards the desirable sub-sample of larger fish, releasing all the smaller and younger fish.

The data analysis to test retention concentrated mainly on comparing length frequency distributions (LFD) between the codends and calculating selectivity curves primarily for the abundant cod and yellowtail flounder species but in some instances for some of the more abundant of the other commercially important species. The non-parametric Kolmogorov-Smirnoff Two-Sample (KS-2) test was used to test for differences between the LFDs.

Selectivity curves were calculated on pooled data for cod, haddock and yellowtail flounder for each of the net types but were not calculated for the 3 inch and 4 inch grates. The total catch from both codends of the grate hauls were used to calculate the reference population for the selectivity curves. In pooling the data, the four control-s tows and the three 6.5 inch square-s tows made on the first day at sea were excluded from the analysis because the codends were modified at the end of the day to correct for possible side bias (see below for explanation).

Selectivity curves for all experimental treatments were calculated using the SELECT Method (Wileman, 1996), as appropriate to analyze paired gear selectivity data.

SEA TRIALS & DATA COLLECTION

The data were collected during two consecutive trips in late May and early June, 2001, totaling 43 hauls in 10 days at sea on Stellwagen Bank. During those trips a total of 8 different gear arrangements were tested, six using two codends in a side-by-side trouser trawl arrangement. Two additional sets of tests were conducted with a 3 inch mesh retaining bag above a 3 inch or 4 inch metal grate with 3 inch mesh codend, behind the grate. All of the codends, the 6 inch diamond control (5mm polyethylene), 6.5 inch square (6 mm ultracross), 6 inch hexagon (6 mm ultracross), and 6.5 inch hexagon (6 mm ultracross), were measured at sea by taking 20 meshes at random and measuring their stretched length. A chaffing mat was attached to the codends to prevent abrasion of the codend twine by the seafloor..

The first four hauls were performed with two identical codends, made of 6 inch diamond meshes, which is the standard mesh used in this fishery. These control hauls were used to test for potential biases of the trouser trawl setup.

The A-B-B-A pattern of alternating codends was followed throughout the trip, whether dealing with a control haul (two identical 6 inch diamond codends) or an experimental haul (one control 6 inch diamond mesh codend and one experimental codend). This is a routine precaution generally taken when operating a trouser trawl. In practice this means the codends were swapped every second haul. In order to facilitate this procedure the codends were attached to the extension of the net by a rope threaded through a series of rings. Using this contrivance it was possible to swap codends in 15 minutes, thereby minimizing time lost to fishing.

The codends equipped with grates operated in a different manner: a grate measuring 54 inches by 40 inches, with horizontal bars every 3 inches (or with vertical bars every 4 inches), was attached obliquely to the entrance of the codend. At the top of the grate, where fish too large to pass through the bars would tend to be forced upwards by water pressure, was a small window cut into the codend similar to the arrangement of the widely used Nordmore grate. A 3 inch diamond mesh retaining bag or cover was then attached to this window to retain fish too large to pass through the bars. Fish passing through the bars were captured in the 3 inch mesh codend behind the grate.

Table 1 provides a description of the gears used during the project.

TABLE 1. CONTROL AND EXPERIMENTAL GEARS.

Experiment	No. of Hauls	No. of codends	Experimental gear tested	Description
Control-S	4	2	none	paired codends, both 6″ diamond mesh
Control-L	4	2	none	paired codends, both 6 diamond″ mesh. Longer split between codends (20′)
6.5″ Sq.-S	3	2	6.5 square ultracross codend	paired codends, 6″ diamond mesh and 6.5″ square mesh
6.5″ Sq.-L	8	2	6.5 square ultracross codend	paired codends, 6″ diamond mesh and 6.5″ square mesh. Longer split (16′)
6″ Hex-L	8	2	6 hexagonal ultracross codend	paired codends, one 6″ diamond mesh, other 6″ hexagonal mesh.
6.5″ Hex-L	8	2	6.5 hexagonal ultracross codend	paired codends, one 6″ diamond mesh, other 6.5″ hexagonal mesh.
3″ grate	4	2	3″ grate	3" mesh codend behind the grate and 3" mesh codend cover above the grate.
4″ grate	4	2	4" grate	3" mesh codend behind the grate and 3" mesh codend cover above the grate.

The main net had a 172' head rope, and utilized 36- 8 inch floats. The footrope was a 194' rubber cookie sweep. The mesh size of the main net was 6 inch polyethylene hung on a diamond. All the codends were measured using an ICES measuring gauge (MARFISH net measuring device). The measurements recorded were the inside (knot to knot). For the hexagon mesh, however, we took additional measurements of the length of each strand.

For 11 out of 43 tows, we used an underwater camera to document behavior. The camera was a Sony digital camcorder in an Amphibico housing; this was placed in a ridged frame with a float to compensate for buoyancy. For the control tows, we placed the camera just before the split. For another 6 tows, the camera was placed on the head rope facing inside the net. When we tested the grid, we positioned the camera a few feet ahead of and facing the grate to observe fishes' behavior at the grate.

The first 7 hauls (4 of which were control and the remaining 3 testing one standard 6 inch diamond mesh codend against a 6.5 inch square mesh codend, all of them using a trouser trawl arrangement) appeared to the operators on deck to show a potential side bias. The codend on the port side always appeared fuller than the other. Videotape taken on the first day indicated that cod were avoiding the darker mesh (ultracross). Some of the sequences showed cod about to enter the darker ultracross codend turning around and rapidly swimming into the lighter colored 6 inch diamond codend. In order to correct for this, the crew modified the length of the split, making the legs of the trouser trawl (before the codend) longer by approximately 20 feet in the control trawls and 16 feet in the trawls collecting data on comparison of the control with the experimental gear. Both the control hauls and the experimental hauls testing the 6.5 inch square mesh codend were repeated with the longer split. The gears before and after the modification to the split were considered separately, for the purposes of data analysis. In pooling the data, the seven hauls made on the first day before the split was extended (control-s and 6.5" Sq-s) were excluded.

After each haul, the catch from each of the two codends or from a grate-equipped codend and its cover where downloaded on deck onto separate checkers. The catch from each codend/cover was processed separately. Observers certified to NMFS standards collected data on the catch of each of the codends, noting in particular the weight kept and discarded for each fish species. The length of every commercially important fish species in the catch was also measured. In cases where very large catches were made, a sub-sample of the catch was measured, representative of the length classes present in the whole catch.

Although not part of our original research plan, Captain Estudante invited Dave Martins, a technician from UMass Dartmouth's School of Marine Science and Technology (SMAST), aboard to tag live codfish. Funded by the Massachusetts Fisheries Recovery Commission, the SMAST Cod Tagging Project uses commercial fishing vessels and their crews to tag codfish in the Gulf of Maine, Georges Bank, and Nantucket Shoals. Recovered tags are used to determine fish migrations, long-term growth, and environmental preferences.

After the cod were weighed and measured, they were placed in three large tubs set up as live wells on deck. Conventional spaghetti tags were inserted below the dorsal fin of all live cod and special data storage tags, containing micro data loggers, which record water depth and temperature, were fastened on the backs of larger cod. A total of 2,754 cod were tagged and released by the SMAST technician, the Manomet observers, and the crew of the Rita Sophia during the experimental tows, the most for any vessel in the Cod Tagging Project. For details of this study contact Dan Holland (Dholland@umassd.edu), Assistant Professor at SMAST.

RESULTS

Of the commercially important species caught consistently in all the treatments in significant quantities, cod and yellowtail formed the largest part of the catch, as well as the most valuable from a commercial point of view. Table 2 lists the total weight in pounds and number of individuals caught for each species in each treatment in the starboard and port sides of the trouser trawl for the treatments testing selectivity of mesh size and shape or in the control (above the grate) and experimental (through the grate) for the treatments testing selectivity of grates.

TABLE 2. WEIGHT AND LENGTH OF INDIVIDUALS OF FISH CAUGHT BY SPECIES AND GEAR

Species	Treatment	Weight (lbs)		No. of individuals	
		Starboard /control	Port/ Experimental	Starboard /control	Port/ Experimental
Cod	Control-S	2525	1993	524	403
	Control-L	1556	1458	317	354
	6.5″ Sq.-S	796	97	444	40
	6.5″ Sq.-L	4420	1011	755	136
	6″ Hex-L	1028	1034.5	274	260
	6.5″ Hex-L	467	410	126	97
	3″grate	684	1190	276	410
	4″grate	2095	2215	918	758
Haddock	Control-S	356	335	64	63
	Control-L	216	253	43	66
	6.5″ Sq.-S	139	13	75	17
	6.5″ Sq.-L	551	138.5	87	11
	6″ Hex-L	157	164.5	32	39
	6.5″ Hex-L	35	1.5	6	1
	3″grate	23	45	13	15
	4″grate	23	132	15	52
Pollock	Control-S	161	178	22	22
	Control-L	84	55.5	13	9
	6.5″ Sq.-S	43	24	9	2
	6.5″ Sq.-L	101.5	46	11	6
	6″ Hex-L	48.5	55.5	7	10
	6.5″ Hex-L	150	129	19	15
	3″grate	28	25	5	3
	4″grate	14	36	3	11

Species	Treatment	Weight (lbs)		No. of individuals	
		Starboard /control	Port/ Experimental	Starboard /control	Port/ Experimental
Yellowtail flounder	Control-S	143	150	155	171
	Control-L	72.5	79	86	82
	6.5″ Sq.-S	52	55	109	127
	6.5″ Sq.-L	175.5	252.5	130	267
	6″ Hex-L	366.5	425	374	439
	6.5″ Hex-L	443	326	456	328
	3″grate	460	170	681	247
	4″grate	106	70	211	105
Winter flounder	Control-S	7	15	11	4
	Control-L	4	5	2	3
	6.5″ Sq.-S	1	6	3	2
	6.5″ Sq.-L	21	23.5	11	16
	6″ Hex-L	26.5	27	18	19
	6.5″ Hex-L	37	30.5	32	27
	3″grate	24	16	27	8
	4″grate	2.5	0	1	0
Dabs	Control-S	15	14	11	12
	Control-L	7	10	4	5
	6.5″ Sq.-S	14	9	15	15
	6.5″ Sq.-L	27	45	16	25
	6″ Hex-L	79	94	62	70
	6.5″ Hex-L	37.5	35	32	25
	3″grate	17.5	5	14	4
	4″grate	29.5	24.5	35	24
Monkfish	Control-S	36	25	6	5
	Control-L	20.5	34	4	5
	6.5″ Sq.-S	4.5	0	8	0
	6.5″ Sq.-L	48	25.5	13	9
	6″ Hex-L	30.5	138	6	10
	6.5″ Hex-L	35.5	74.5	8	24
	3″grate	3	3	1	1
	4″grate	4.5	34.5	2	8

The data analysis was concentrated mainly on length frequency distributions (LFD) and selective efficiency of the various codend configurations. After pooling the data for each treatment, the LFDs of each species in the two codends (and around and through the grates) were compared by applying the Kolmogorov-Smirnov Two-Sample test. This non-parametric test was used to reveal significant differences between the distributions such as location, dispersion, and skewness of two populations (Sokal and Rohlf, 1995). For completeness, this test was also used to compare LFDs between codend and cover.

The following table summarizes the results obtained with the KS-2 test on pooled data for each treatment.

TABLE 3. SIGNIFICANCE FOR KOLMOGOROV-SMIRNOV TWO-SAMPLE TEST FOR POOLED DATA FROM EACH TREATMENT.

species	cntrol-S	cntrol -L	6.5″ sq-S	6.5″ sq-L	6″hex-L	6.5″hex-L	3" grate	4" grate
cod	***	NS	***	***	NS	NS	NS	*
haddock	NS	NS	***	**	NS	NA	NS	NS
pollock	NS	NS	NS	NS	NS	NS	NS	NS
yellowtail	*	NS	NS	NS	NS	NS	**	*
winter	NS	NA	NA	NS	NS	NS	NS	NA
dab	NS	NS	NS	*	NS	NS	NS	NS
monkfish	NS	NS	NA	NS	NS	NS	NA	NS

**P* < .05, ***P* < .01, ****P* < .001

The LFDs between two identical codends, such as those used in the control treatments, were not expected to be significantly different. For two major species, cod and yellowtail flounder, however, significant differences were present with control-S, where both codends used the same 6 inch -diamond mesh netting. This confirmed the observations of a potential side bias observed by the operators on deck during fishing operations. The modifications of adding a split or extension before the codends appear to have corrected this bias, since no significant differences surfaced for the control-L treatment.

Cod and haddock retained by the experimental codends made of 6.5 inch sq mesh also had significantly different LFDs from their control codends, both before (6.5" sq-S) and after (6.5" sq.-L) the modifications to the length of the split. However, since it is impossible to separate the effect of the side bias from that of the experimental treatment, only the results obtained after the modification to the length of the split are considered valid.

In the case of the grates, significant differences between fish retained in the codend and fish caught in the cover were expected, in terms of LFDs, since the purpose of the grates was to let small fish escape from the codend. It is interesting to note that this was not true for most of the species. The lack of significance may have been due to the generally small size or small number of that species caught but may also indicate that the selected bar spacing was not appropriate for selecting the species in question.

The Kolmogorov-Smirnov Two Sample test results and the descriptive statistics for the control and experimental codends for each of the eight experiments are summarized in Table 3a and 3b for cod and yellowtail flounder. See Appendix B for LFDs for control and experimental gear in each treatment for cod and yellowtail flounder.

TABLE 3A. COD CATCH STATISTICS FOR EACH CODEND OF THE 8 EXPERIMENTS.

COD	Control Short		Control Long		6.5"Sq Long		6.5"Sq Long	
Codend	Port	Strbrd	Port	Strbrd	Control	Exprmtl	Control	Exprmtl
K-S Sig.Lv.	P<.001		N.S.		P<.001		P<.001	
No. of Tows	4	4	4	4	3	3	8	8
No. of Fish	403	525	354	317	444	40	755	136
Ttl.Wt.(lbs)	1993	2525	1458	1556	796	97	4420	1011
COD	6"Hex Long		6.5"Hex Long		3"Grate horizntl		4"Grate vertical	
Codend	Control	Exprmtl	Control	Exprmtl	Control	Cover	Control	Cover
K-S Sig.Lv.	NS		NS		N.S.		P<.05	
No. of Tows	8	8	8	8	4	4	3	3
No. of Fish	274	260	126	97	276	410	918	758
Ttl.Wt.(lbs)	1028	1034	467	410	684	1190	2095	2215

TABLE 3B. YELLOWTAIL CATCH STATISTICS FOR EACH CODEND OF THE 8 EXPERIMENTS.

YT Flounder	Control Short		Control Long		6.5"Sq Long		6.5"Sq Long	
Codend	Port	Strbrd	Port	Strbrd	Control	Exprmtl	Control	Exprmtl
K-S Sig.Lv.	P<.05		N.S.		N.S.		N.S.	
No. of Tows	4	4	4	4	3	3	8	8
No. of Fish	171	155	82	86	109	127	130	267
Ttl.Wt.(lbs)	150	143	79	72	52	55	176	252
YT Flounder	6"Hex Long		6.5"Hex-Long		3"Grate horizntl		4"Grate vertical	
Codend	Control	Exprmtl	Control	Exprmtl	Control	Cover	Control	Cover
K-S Sig.Lv.	N.S.		N.S.		P<.01		P<.05	
No. of Tows	8	8	8	8	4	4	3	3
No. of Fish	374	439	456	328	681	247	211	105
Ttl.Wt.(lbs)	366	425	443	326	460	170	106	70

It is possible to estimate the actual selectivity of a codend, by estimating the length at which 50% of the individuals are released (L50) and the selection range (SR) (defined as L75-L25), which is a measure of the steepness of the slope and hence the selective efficiency of the codend.

Selectivity curves for all experimental treatments were calculated using the SELECT Method (Wileman, 1996), as appropriate to analyze paired gear selectivity data. Given the presence of replicate hauls for the same gear, hauls were combined, then the total catch was estimated and the data pooled. The selectivity curve resulting from a combined hauls analysis gives the mean selection curve for the gear tested (Wileman, 1996).

The alternate haul SELECT Method was used to calculate the selectivity curves and parameters. The SELECT Method produces selectivity curves and provides values for the L50, the selection range (SR) and the selection factor (SF). The L50 value is the length (in cm) at which 50% of the individuals of that length escape capture. The SR is the range between L25 to L75. The smaller the SR the steeper is the cumulative capture curve and the more size discriminating is that gear type. However, small sample size can also affect the SR value. The SF is a measure of the relationship between mesh size and the calculated L50. Specifically, the SF is calculated by dividing the mesh size by the L50. The SF values give an indication of the 'goodness of fit' of the selectivity curve. For example, for roundfish, the SF values are generally values in the range 2 – 4. Selection Factor is generally meaningless when applied to hexagonal codends and is not presented here. Selectivity parameters were calculated for cod, haddock and yellowtail flounder for the four experimental codends (Table 4).

TABLE 4. SELECTIVITY PARAMETERS FOR COD, HADDOCK AND YELLOWTAIL FLOUNDER. IN CENTIMETERS

		Cod		
Codend Type:	6"Diamond	6.5"Square	6"Hex	6.5"Hex
L50	49.1	60.2	53.7	61.4
SR	5.7	7.2	12.2	9.9
SF	3.2	3.7	NA	NA
MLS	48	48	48	48
		Haddock		
Codend Type:	6"Diamond	6.5"Square	6"Hex	6.5"Hex
L50	50.6	55.7	46.0	No Data
SR	6.3	6.4	0.8	No Data
SF	3.3	3.4	NA	No Data
MLS	48	48	48	48
		Yellowtail Fl		
Codend Type:	6"Diamond	6.5"Square	6"Hex	6.5"Hex
L50	38.6	34.5	39.5	34.6
SR	7.8	5.0	6.7	4.9
SF	2.5	2.1	NA	NA
MLS	33	33	33	33

L50 is the total length of the fish at which 50% of the individuals of that length class escape capture; SR is the selection range (in cm) between L75 and L25; SF is the selection factor for L50's per cm for that gear type; and the minimum legal size (MLS) is included for reference.

These parameters can be more easily understood and compared when looking at the relative selectivity curves. In general, the 'goodness' of a selectivity curve is judged by the proximity of the L50 to the minimum legal size (MLS) for that species and the selection range being as small as possible (that is, knife edge selection where selection range is effectively 0. This however is rarely if ever achieved in practice). However, the interpretation is often subjective: industry representatives may prefer an L50 as close as possible to the MLS, in order not to lose valuable marketable fish above the MLS, while a management or conservation point of view, would prefer an L50 above the MLS, as this reduces the number of fish captured below the MLS.

The selectivity curves for cod, each show an L50 above the MLS (currently 48 cm) See Fig. 1. By looking at the values for the L50 and the SR, it appears that the 6 inch diamond codend is the most selective codend in this trial, because the L50 is just above the MLS and the SR small. A more conservation- oriented alternative would be the 6.5 inch square codend or the 6.5 inch hexagonal mesh, which have higher L50 with a small SR and where no fish below the MLS are retained.

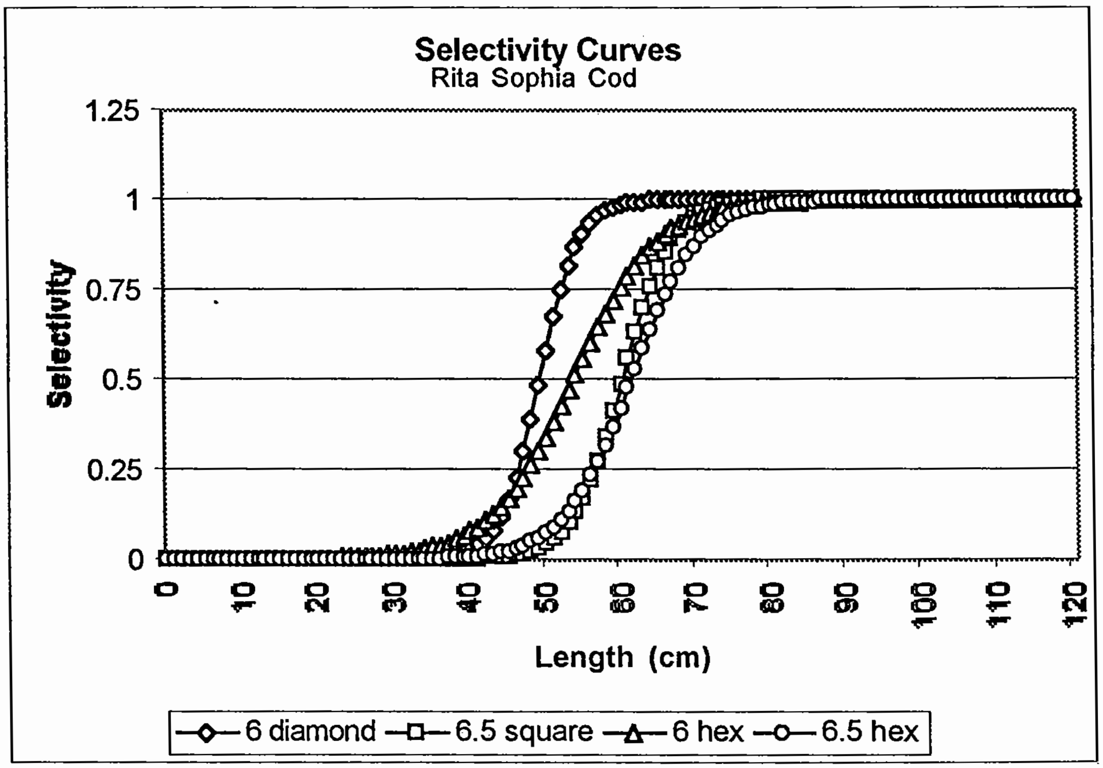


FIGURE 1. SELECTIVITY CURVES FOR COD FOR CONTROL AND EXPERIMENTAL CODENDS

The selectivity curves for haddock also show L50s above MLS (currently 48 cm) for the 6 inch diamond and the 6.5 inch square codend (Figure 2). The data for hexagonal codend were too scarce to build reliable curves. The two standard codends are similar in their selectivity parameters. However, for conservation purposes, the 6.5 inch square codend is a better option, in that it gives a higher L50 with a small SR and almost no fish below MLS are retained. The 6.5 inch diamond retains a proportion of fish below the MLS and is therefore less effective than the 6.5 square mesh codend..

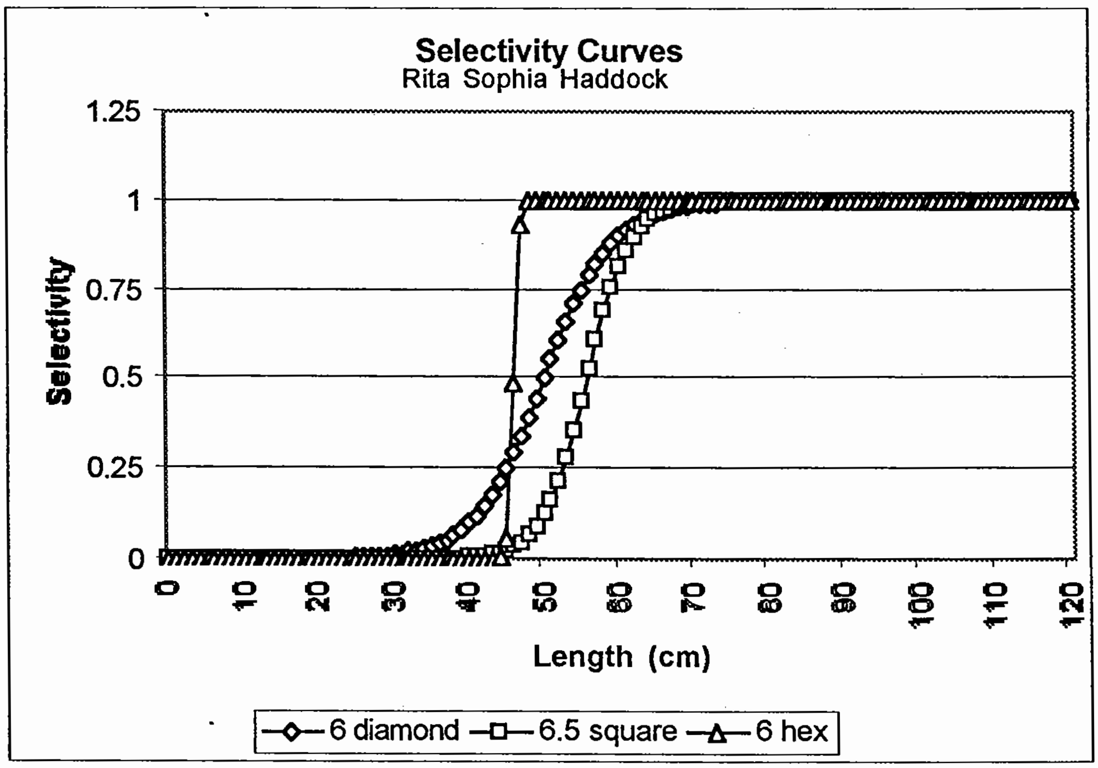
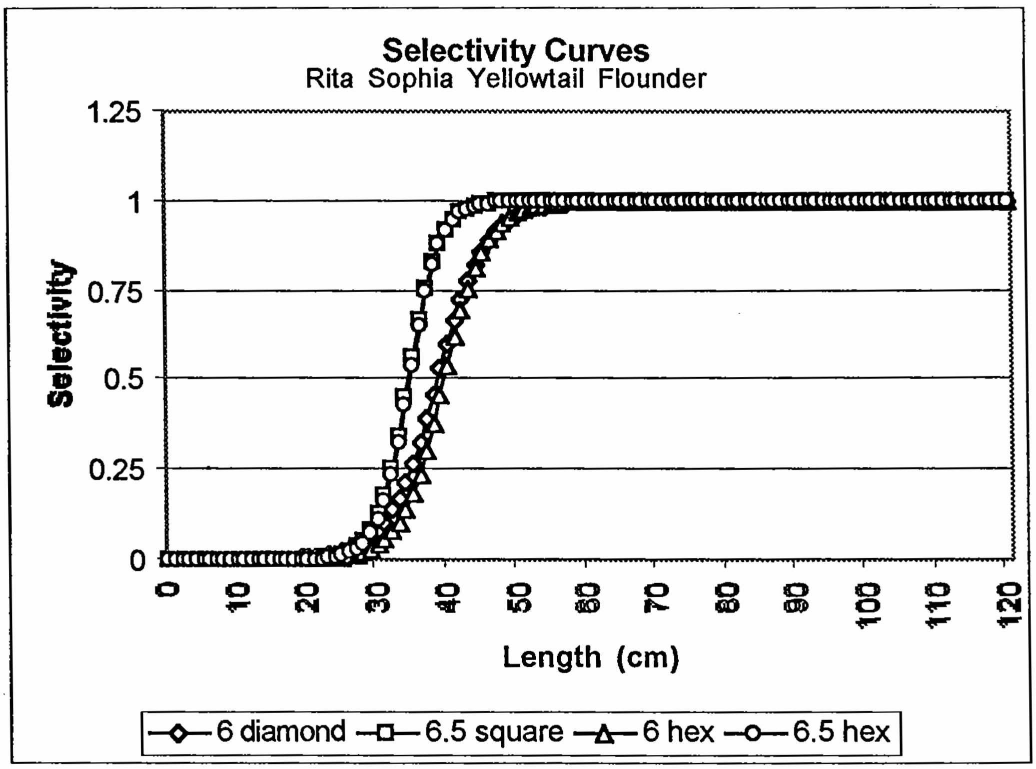


FIGURE 2. SELECTIVITY CURVES FOR HADDOCK FOR CONTROL AND EXPERIMENTAL CODENDS

The selectivity curves for yellowtail flounder also show L50s above MLS (currently 33 cm). The 6.5 inch square and the 6.5 inch hexagonal codends have the L50s closest to the MLS and small SR, making them a good choice, while the 6 inch diamond and the 6 inch hexagonal codend have higher selectivity parameters. However, yet again, despite higher selectivity parameters, the 6 inch hexagonal and 6 inch diamond mesh codends retain fewer fish below MLS and may therefore be a more appropriate mesh configuration for management purposes.



.FIGURE 3. SELECTIVITY CURVES FOR YELLOWTAIL FLOUNDER FOR CONTROL AND EXPERIMENTAL CODENDS

Length frequency distributions and selectivity curves by gear for cod and yellowtail flounders are shown in Appendix C. Selectivity curves by species for each gear type are shown in Appendix D.

DISCUSSION

As stated in the introduction, one of the main goals of this study was to test hypotheses about escapement by species and size of individuals through different size and shape of webbing in the codend. While many commercially important species were encountered in the trials, only cod and yellowtail flounder were consistently caught in quantities large enough to ensure an adequate sample size for the statistical analysis and selectivity study. Haddock was caught in moderately large quantity. Therefore, even though the data were processed for all species and the relative results were presented, the discussion will be limited to cod, haddock and yellowtail flounder.

Retention rates for different types of meshes were explored using a trouser trawl that allowed us to compare directly the contents of the control codend (6 inch diamond) to the contents of the experimental codend in terms of LFDs. The experimental codends differed from the control not only in mesh size and shape, but also in netting material, since ultracross netting was used for the experimental codends, while the control codend was made of polyethylene. As explained in the introduction, ultracross netting is supposed to facilitate escapement and reduce injuries and mortality in the fish that go through the knotless meshes. Ultracross netting material can be made in various shapes and it was of particular interest to this study to explore the effects of hexagonal meshes on size and species selection. As mentioned before, several studies have shown that square meshes retain more flatfish, while diamond meshes retain more roundfish. This is probably due to the fact that square meshes remain open under tension, when towed, while diamond meshes tend to close. Therefore, it is easier for roundfish, like cod and haddock, to escape from square meshes than from diamond meshes.

This study has confirmed this, since the LFDs of cod and haddock in a 6.5 sq codend were significantly different than in the control codend: fewer but bigger fish were retained in a 6.5 inch square mesh codend than in the 6 inch diamond mesh codend. Hexagonal knotless meshes potentially present an interesting intermediate shape between square and diamond shaped meshes. When correctly hung, hexagonal meshes should retain their original shape. However, , during the present study, it appears the codends made of hexagonal meshes were hung in a manner that allowed them to take a shape very similar to diamond mesh netting. Further, net manufactures measure the hexagon mesh as the length of the stretched mesh plus one extra leg. This measurement is particular to so-called multi-legged meshes and results in occasional confusion regarding actual as opposed to nominal mesh sizes. The 6.5 inch hexagon stretched mesh averaged 5.9 inches and the 6 inch hexagon stretched mesh averaged 5.5 inches. The 6 inch diamond stretch mesh averaged 6 inches and the 6.5 inch square averaged 6.5 inches. Therefore, in this case, it is possible that the 6.5 inch hexagonal mesh codends appeared very similar to the 6 inch diamond codends, while the 6 inch hexagonal mesh codend may have appeared like a 5.5 inch diamond mesh codend. This would explain the lack of significant results when comparing the control diamond codend and the experimental hexagonal codends in terms of LFDs. This is an area of research that requires further examination.

The other main goal of the study was to explore escapement by species and size of individuals through rigid grates. In particular, this study aimed at determining whether grates can be used to separate flatfish from roundfish. The opening above the grates were covered with a small mesh cover, so that it would be possible to account for all fish that were excluded by the grate. The horizontal grate, with bars 3 inches apart, was effective at diverting the larger yellowtail flounder, while having no detectable effect on cod and haddock. More work needs to be done to confirm these results, but it appears that such a grate could be used to target selectively larger flatfish while releasing roundfish and smaller flatfish. The vertical grate, with bars 4 inches apart, was effective at diverting both larger yellowtail and larger cod. So, while this type of grate was not effective at species separation, it did show potential for size separation.

In the case of haddock, samples were small, and no size selection was apparent for either grates. These preliminary results in the use of grates for species and size separation are promising and would need to be explored further. In particular, it would be interesting to explore the relative effectiveness of the orientation of the bars, of the bar spacing and the combination of these two factors in the selection process.

The retention rates of the various experimental codends used in the trouser trawl were quantified by their respective selectivity curve. In the case of cod and haddock, the

6 inch diamond codend would release approximately 50% of the MLS fish, as the L50 is very close to MLS. Although this means that most of the marketable catch is retained, it also means that certain portion of the catch will be made of sub legal fish that will need to be discarded at sea. To reduce discard rates of cod and haddock, the selectivity study confirmed that a 6.5 inch square mesh codend is more effective, placing the 50% retention point at 60 cm for cod and at 56 cm for haddock, considerably above MLS.

In the case of yellowtail flounder, results can be interpreted using the same logic: while the 6.5 inch square mesh codend had the L50 closest to the MLS, the 6 inch diamond would be more effective at reducing discard rates of sub legal fish. It is interesting to note that in the case of yellowtail flounder, the 6 inch hexagonal mesh codend performed virtually the same as the 6 inch diamond mesh codend, confirming that their respective hanging ratios made them similar in appearance and function. However, this does not appear to be true to the same degree for cod.

Overall, the program of research has produced a number of significant findings. Clear differences are evident in the selective efficiency of different mesh types and configurations. Some of these differences are self-evident. That is, diamond meshes in general are more effective at releasing flatfish while square and hexagonal meshes are more effective at releasing roundfish such as cod and haddock. However, many of the experimental comparisons were not significantly different for a number of species. It is not immediately obvious why this is the case, but it may indicate either that there is less difference between say square mesh and diamond mesh, than would be expected or more likely that between haul variability is masking the true nature of the effect. Increased sample size would help elucidate such differences.

Hexagonal mesh has been studied extensively in other countries and has been shown to be effective in reducing bycatch in a number of fisheries. Here we found hexagonal mesh to perform less well than anticipated. Hanging aspect or ratio is critical for correct functioning of hexagonal mesh. Meshes can take a number of shapes, including elongate diamond, depending on how the meshes are attached to the meshes of the main body of the net. It is likely that the meshes during this study adopted a diamond shape and this may indeed account for the surprising performance of the hexagonal mesh.

It is clear that hexagonal mesh is effective to a certain degree in helping to reduce bycatch, however more research is needed both in terms of hanging ratio and appropriate mesh size before introduction into multi-species fisheries.

The selection grates investigated in this study indicated the potential effectiveness of grates as size sorting devices. However, grates are generally less effective as species sorting devices except where there are either major differences in behavior between target and non-target species, or where there are major differences in body shape between target and non-target species for example shrimp and fish. The results presented here suggest that rigid grates may be used effectively as size sorting devices (and hence bycatch reduction tools) but overall the results are inconclusive and much more work is required.

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APPENDIX A. FISHING LOG OF THE RITA SOPHIA

Date	Time Tow	Duration	LAT	LON	WIND	SEA	SEA WAT TEMP	FM	WIRE	PORT	REMARKS
5/23	15 30	Wed								LEAVE NB	DAY 1
5/24	6:55	Thu	42 09.90	70 10.90				23	100		FN 45FM GC
1	1	514									
6"D	A	6"D									
5/24	7:31	0:36	42 10.50	70 08.50				25			
5/24	8:51	Thu	42 10.70	70 08.20				25	100		
2	2	514	42 11.00	70 07.20				26			
6"D	B	6"D	42 11.60	70 06.80				29			
5/24	9:52	1:01	42 13.20	70 08.10				27			
5/24	10:29	Thu	42 13.40	70 08.50				27	100		
3	3	514	42 11.50	70 06.80				29			
6"D	B	6"D									
5/24	11:31	1:02	42 10.70	70 08.20				26			
5/24	12:33	Thu	42 10.60	70 08.30				26	100		
4	4	514									
6"D		6"D									
5/24	13:13	0:40	42 09.90	70 11.30				22			
5/24	17:25	Thu	42 10.10	70 09.90				24	100		17:25-17:35
5	5	514									17:56-18:04
3"	H	3"	42 10.10	70 10.70				23			
5/24	18:04	0:18	42 10.50	70 09.10				23			
5/24	20:45	Thu								PTOWN	
											DAY 2
5/25	6:45	Fri								LEAVE PTOWN	
5/25	8:32	Fri	42 09.70	70 12.00				20	100		6-6.5
6	6	514									
6D		6.5S									
5/25	9:22	0:50	42 10.60	70 08.30				25			
5/25	10:39	Fri	42 11.00	70 07.40				25	100		6.5-6
7	7	514									VIDEO SHOWS UNEVEN FLOW-FISH RUNNING FR BLK CODEND
6.5S	B	6D									EXTEND SPLIT 31M INTO EXTENSION
5/25	11:24	0:45	42 13.20	70 08.10				27			PART ST GC ON SET-OUT
5/25	14:36	Fri	42 11.00	70 07.70				25	100		6.5-6
8	8	514									CAM PICT NOT CLEAR
6.5S	B	6D									DISTRIB SEMS EVEN
5/25	15:19	0:43	42 12.90	70 08.00				28			DOGFISH
5/25	16:26	Fri	42 11.20	70 06.90				27	100		A - '6-6
9	9	514									STB WIRE ALONG BEG TOW, BOTH SPREAD TO END OF TOW
6D		6D									DOGFISH
5/25	17:09	0:43	42 10.30	70 09.60				25			ST MORE COD
5/25	18:15	Fri	42 11.60	70 07.20				27	100		B - 6-6
10	10	514									STB WIRE ALONG BEG TOW, TO PT MOST OF TIME
6D	B	6D									VERY FEW DOGFISH
5/25	18:45	0:30	42 13.00	70 08.20				26			ST
5/25	19:25	Fri	42 12.70	70 07.80				28	100		B-6-6

Date	Time Tow	Duration	LAT	LON	WIND	SEA	SEA WAT TEMP	FM	WIRE	PORT	REMARKS
11	11	514									PT CLOSER, ALMOST ALONSIDE, BOTH TO ST AT END 5 MIN+
6D	B	6D									
5/25	19:58	0:33	42 11.00	70 07.40				25			ST
5/25	20:49	Fri	42 10.50	70 09.20				23	100		A6-6
12	12	514									WIRES STRAIGHT
6D	A	6D									
5/25	21:25	0:36	42 09.90	70 12.10				19			PT MORE COD
5/25	22:20	Fri								PTOWN	P'TOWN
											DAY 3
5/26	6:45	Sat								LEAVE PTOWN	LEAVE P'TOWN
5/26	8:37	Sat	42 09.80	70 11.90				19	100		6.5-6
13	13	514	42 10.70	70 08.00				25			
6.5S	B	6D	42 11.20	70 06.90				26			
5/26	10:04	1:27	42 12.10	70 07.20				30			ST MORE COD
5/26	10:56	Sat	42 13.30	70 08.30				27	100		
14	14	514									
6D	A	6.5S									
5/26	11:48	0:52	42 10.90	70 07.60				25			PT MORE COD
5/26	12:17	Sat	42 10.80	70 07.90				25	100		
15	15	514									
6D	A	6.5S									
5/26	13:24	1:07	42 13.90	70 08.70				29			PT MORE COD
5/26	14:23	Sat	42 13.30	70 08.30				28	100		
16	16	514	42 11.00	70 07.00				27			
6.5S	B	6D									
5/26	15:30	1:07	42 10.70	70 08.20				26			
5/26	16:18	Sat	42 10.60	70 08.80				25	100		CAMERA
17	17	514									
6.5S	B	6D									
5/26	17:06	0:48	42 12.30	70 07.30				31			
5/26	17:55	Sat	42 11.50	70 06.70				29	100		
18	18	514									
6D	A	6.5S									
5/26	18:41	0:46	42 13.60	70 08.50				28			
5/26	19:07	Sat	42 13.30	70 08.50				27	100		
19	19	514									
6D	A	6.5S									
5/26	20:14	1:07	42 10.60	70 08.30				25			
5/26	21:03	Sat	42 10.80	70 07.40				25	100		
20	20	514									
6.5S	B	6D									
5/26	22:03	1:00	42 09.90	70 12.10				19			DAY 4
5/27	4:45	Sun								NB	DAY 5

Date	Time Tow	Duration	LAT	LON	WIND	SEA	SEA WAT TEMP	FM	WIRE	PORT	REMARKS
5/28	19:00	Mon								LEAVE NB	DAY 6
5/29	1:00	Tue								PTOWN	
										UNLOAD	
5/29	8:30	Tue								LEAVE PTOWN	
5/29	10:38	Tue	42 10.20	70 10.40				23	100		CAMERA
1	21	514									
6.5H	A	6D									
5/29	11:43	1:05	42 12.40	70 07.50							
5/29	12:32	Tue	42 12.30	70 07.60				28	100		CAMERA
2	22	514									
6D	B	6.5H									
5/29	13:47	1:15	42 10.00	70 11.30				20			
5/29	14:24	Tue	42 09.50	70 13.30				28	100		CAMERA MIDWING - SHOWS CENTER
3	23	514									
6D	B	6.5H									
5/29	15:49	1:25	42 11.20	70 07.20				27			
5/29	16:32	Tue	42 11.00	70 07.20				27	100		
4	24	514									
6.5H	A	6D									
5/29	17:50	1:18	42 09.50	70 12.80				26			
5/29	19:14	Tue	42 10.30	70 09.80				25	100		
5	25	514									
3"	H	3"									ROCK IN EXTENSION. BROKE CRATE
5/29	19:39	0:25	42 10.70	70 08.00				26			
5/29	22:15	Tue								PTOWN	
											DAY 7
5/30	5:30	7:15								LEAVE PTOWN	
5/30	7:44	Wed	42 10.30	70 09.70				25	100		CAMERA
6	26	514									
3"	H	3"									**CRATE REPAIRED W/ TAPE BUT LOWER OPENING WIDER**
5/30	8:12	0:28	42 11.00	70 07.50				25			
5/30	9:32	Wed	42 10.90	70 07.20				25	100		
7	27	514									
6.5H	A	6D									
5/30	10:57	1:25	42 09.50	70 13.30				28			
5/30	11:40	Wed	42 09.90	70 11.80				19	100		CAMERA MIDWING, FURTHER UP
8	28	514									
6D	B	6.5H									TORN WING
5/30	13:10	1:30	42 12.50	70 07.60				28			OLD LOB POT IN BELLY
5/30	15:02	Wed	42 12.60	70 07.10				28	100		CAMERA ON CENTER
9	29	514									
6D	B	6.5H									
5/30	16:32	1:30	42 09.90	70 11.20				22			
5/30	17:15	Wed	42 09.70	70 12.50	NW15	3	11.0	21	100		

Date	Time Tow	Duration	LAT	LON	WIND	SEA	SEA WAT TEMP	FM	WIRE	PORT	REMARKS
10	30	514									
6.5H	A	6D									
5/30	18:45	1:30	42 11.90	70 07.20				29			
5/30	21:45	Wed						25		PTOWN	
											DAY 8
5/31	6:15	8:30			NW25	6				LEAVE PTOWN	
5/31	8:26	Thu	42 09.90	70 12.20	NW25	6		20	100		
11	31	514									
6H	A	6D									
5/31	10:06	1:40	42 12.60	70 07.50				30			
5/31	10:47	Thu	42 12.70	70 07.50	NW20	5		30	100		CAMERA ON CENTER
12	32	514									
6D	B	6H									
5/31	12:17	1:30	42 10.00	70 10.60	NW20	4					
5/31	12:50	Thu	42 10.00	70 10.60	NW20	4	9.0	23	100		CAMERA ON CENTER
13	33	514									
6D	B	6H									
5/31	14:20	1:30	42 13.30	70 07.80	NW20	3		30			
5/31	15:04	Thu	42 13.10	70 08.20	NW15	3	9.5	27	100		
14	34	514									
6H	A	6D									
5/31	16:34	1:30	42 09.10	70 10.80	NW10	3		24			
5/31	17:45	Thu	42 10.90	70 07.80	NW10	3		25	100		
15	35	514									
3"	H	3"									**LOWER BAR MISSING**
5/31	18:15	0:30	42 10.10	70 10.20	NW10	2		25			
5/31	20:45	Thu								PTOWN	
											DAY 9
6/1	6:30	9:45								LEAVE PTOWN	
6/1	8:16	Fri	42 09.80	70 11.80	NNW5-10	1	50F	21	100		
16	36	514									
6H	A	6D									
6/1	9:52	1:36	42 12.70	70 07.50				31			
6/1	10:57	Fri	42 12.40	70 07.20	W5	1-	9C	32	100		CAMERA ON CENTER
17	37	514									
6D	B	6H							120		
6/1	12:27	1:30	42 08.00	70 03.00				30			
6/1	13:02	Fri	42 08.50	70 03.20	CALM	FLAT	9C	32	120		
18	38	514									
6D	B	6H									
6/1	14:02	1:00	42 05.40	70 05.80				34			
6/1	15:02	Fri	42 11.30	70 06.30	SE5	1-		29	120		
19	39	514									
6H	A	6D									

Date	Time Tow	Duration	LAT	LON	WIND	SEA	SEA WAT TEMP	FM	WIRE	PORT	REMARKS
6/1	16:07	1:05	42 08.30	70 03.30				29			
6/1	17:18		42 09.00	70 03.70	SSE5	1-		31	120		
20	40	514									
3"	V	3"									
6/1	17:48	0:30	42 11.00	70 04.00	SSE5	1-		31			
6/1	20:25									PTOWN	
											DAY 10
6/2	5:15	8:50								LEAVE PTOWN	
6/2	7:43		42 08.90	70 03.50	SE10	3		34	120		OVERCAST - DRIZZLE
21	41	514									
3"	V	3"									
6/2	8:00	0:17	42 09.80	70 04.10	SE20	6		32			MEASURING, WEIGHTING, TAGGINF FISH
6/2	9:53		42 09.10	70 03.70	SE20	6		32	120		
22	42	514									
3"	V	3"									ST DOOR ON ITS BACK
6/2	10:01	0:08	42 08.70	70 03.50				32			
6/2	10:34		42 09.50	70 04.00	SE20	6		32	100		
23	43	514							120		
3"	V	3"									
6/2	10:44	0:10	42 10.20	70 04.20				33			
6/2	13:45									PTOWN	
6/2	14:15	0:30								LEAVE PTOWN	
6/2	23:45									NB	

Appendix B: Length Frequency Distribution for Cod and Yellowtail for each Treatment.

The following graphs show the length frequency distributions (LFD) of cod, haddock and yellowtail flounder in each of the treatments. Each graph shows the LFDs of that fish species in the two codends used in that treatment, as the title of each graph details (e.g. 'Haddock LFD in 4" grate experiment' shows the LFD of the haddock caught during the 4" grate experimental treatment, both in the cover and in the codend). The contents of the two codends are shown in a mirror layout for ease of comparison. At the right hand side of each graph, the legend identifies which color corresponds to each codend and the total number of individuals in that codend. Each bar corresponds to a 1 cm length class (x axe).

NUMBER= number of individuals (left y axe)

Proportion per Bar= proportion of the catch for each length class (right y axe)

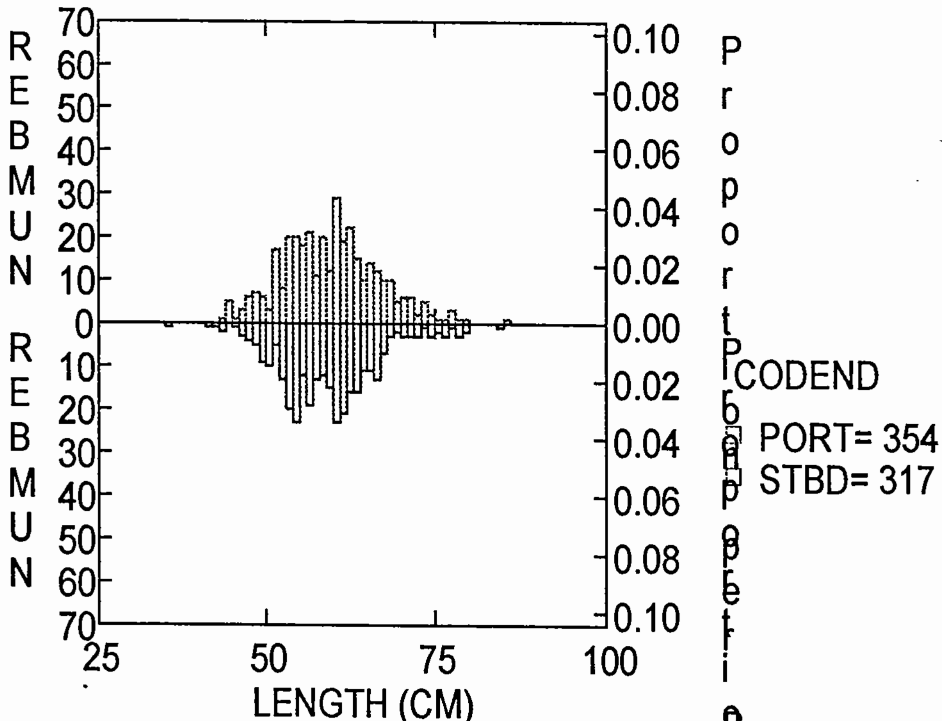
CODEND, PORT / STBD= in the control tows, the contents of the codends were pooled according to the side the codends were fishing, port or starboard (STDB).

MESH, EXP / STD= in the tows where experimental codends were tested, the contents of the codends were pooled according to mesh size/shape, EXP for 6.5 sq. 6 hex and 6.5 hex, STD for 6 diamond.

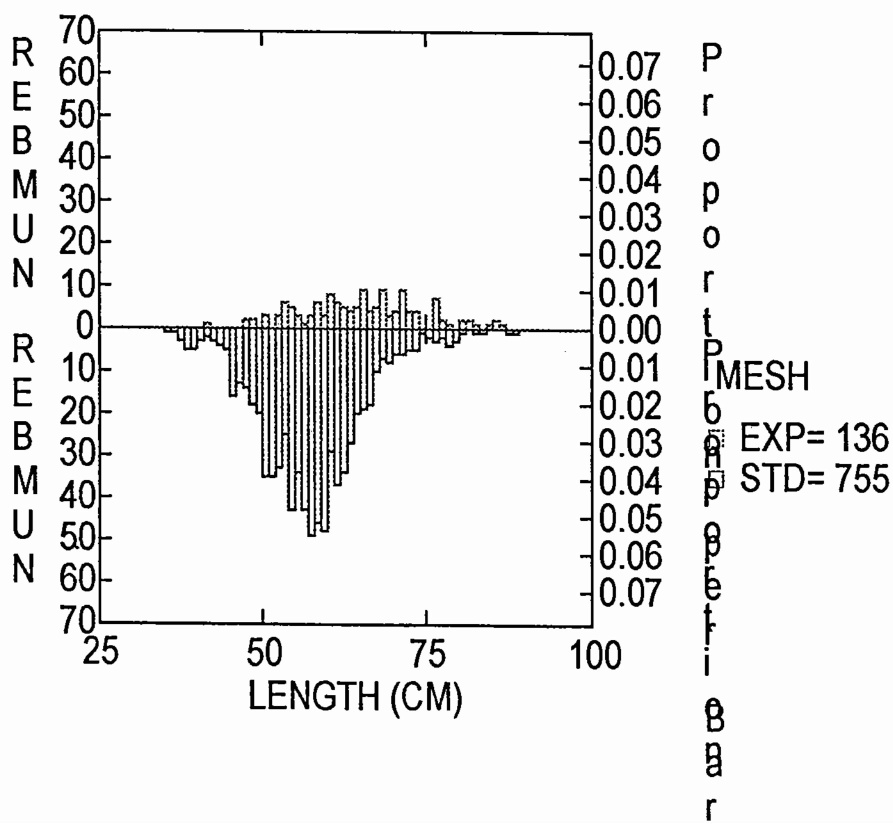
GRATE3, CODEND / COVER= in the tows where the 3" grate was tested, the contents of the codends were pooled according to the side of the grate they were attached to, COVER for the codend on top of the grate, CODEND for the codend on the bottom of the grate.

MESH, CODEND / COVER= as above, but applied to the 4" grate.

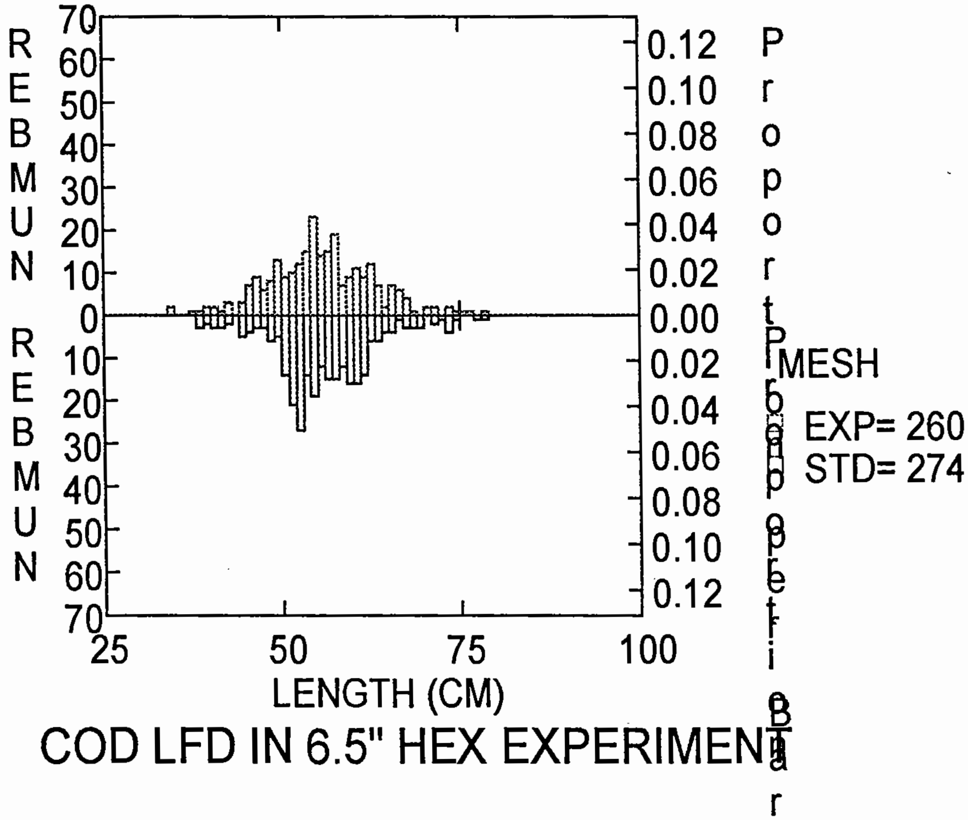
COD LFD IN CONTROL1 EXPERIMENT



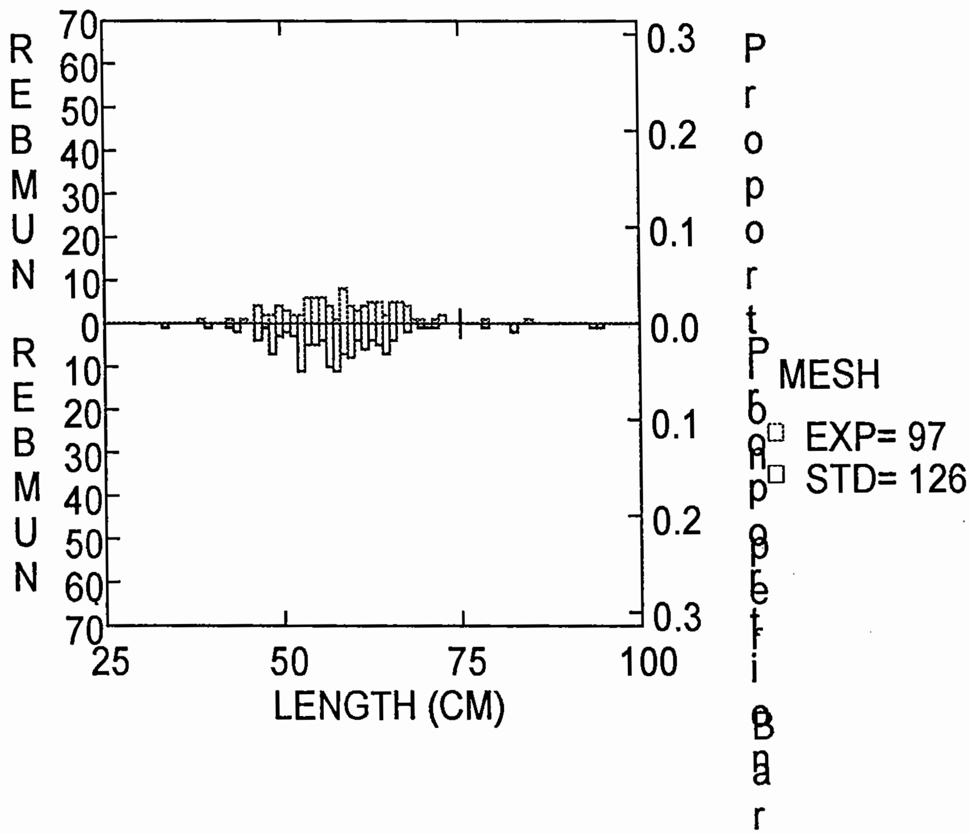
COD LFD IN 6.5" SQ1 EXPERIMENT



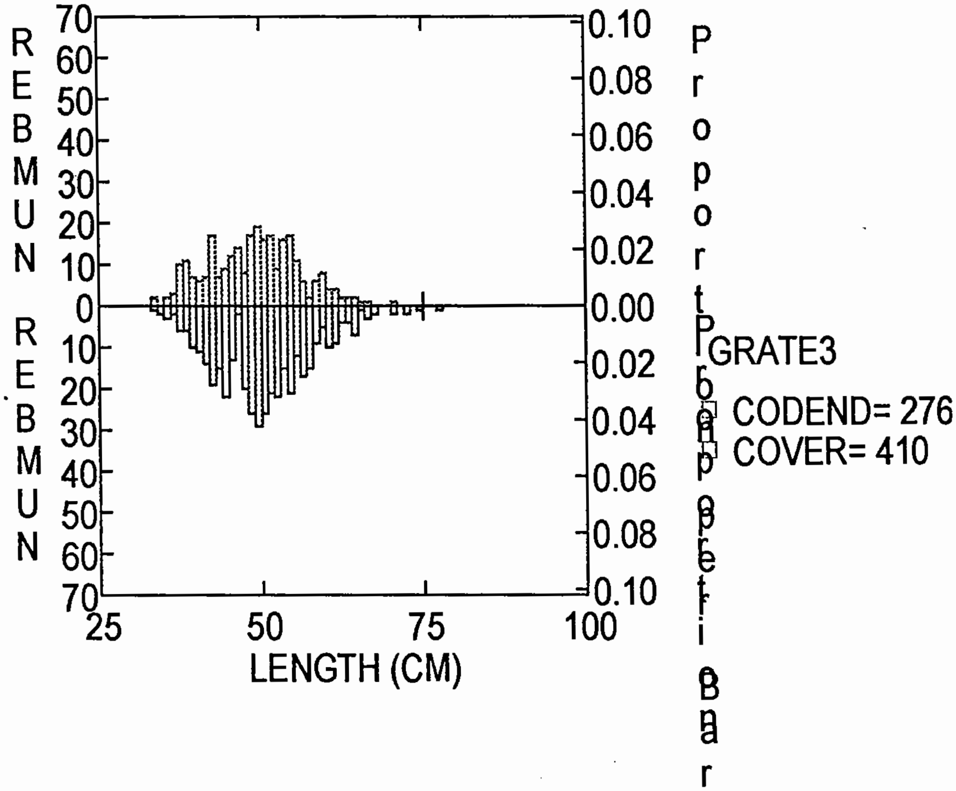
COD LFD IN 6" HEX EXPERIMENT



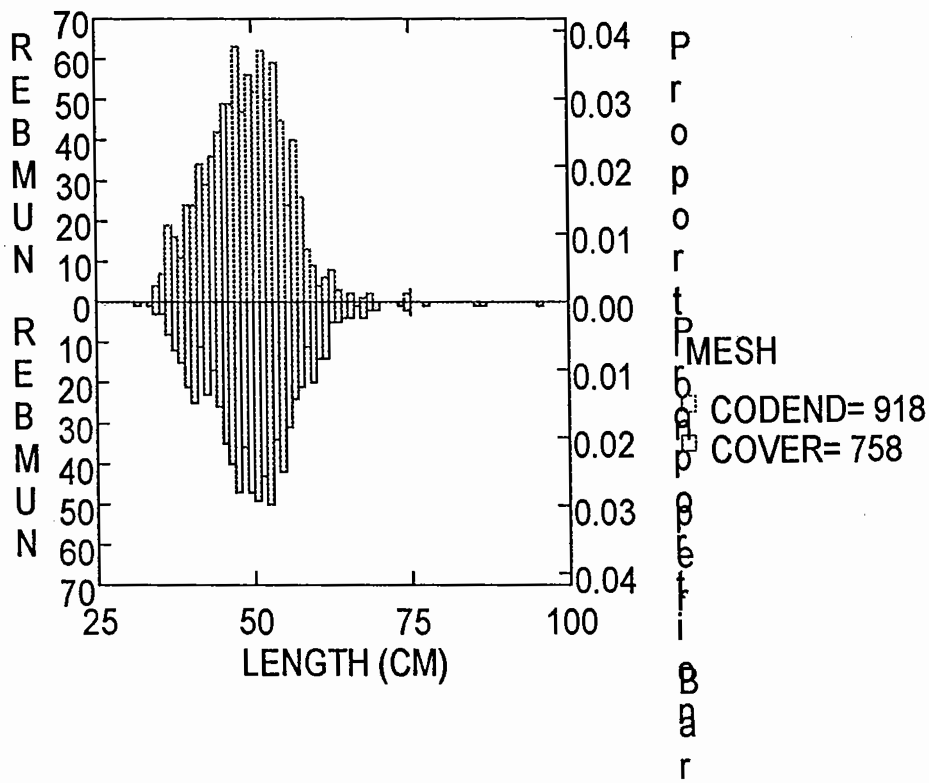
COD LFD IN 6.5" HEX EXPERIMENT



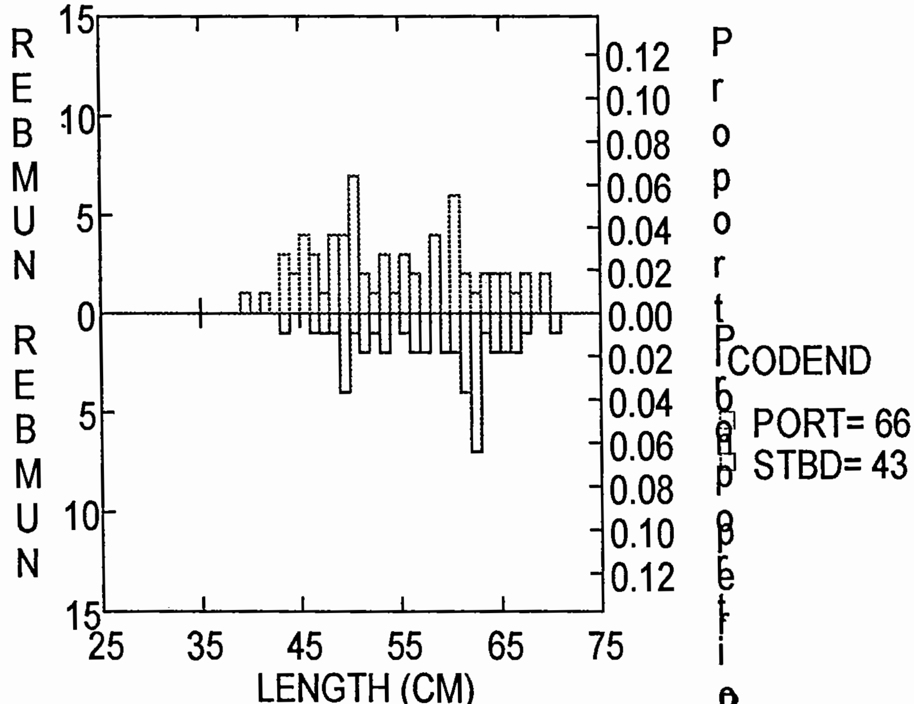
COD LFD IN 3" GRATE EXPERIMENT



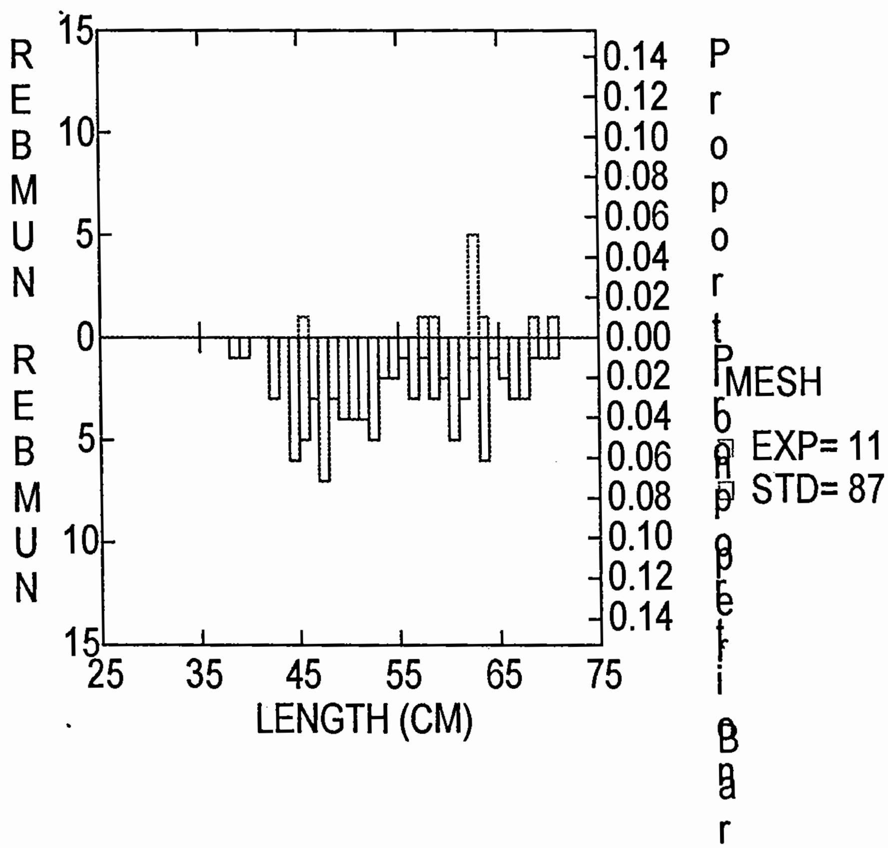
COD LFD IN 4" GRATE EXPERIMENT



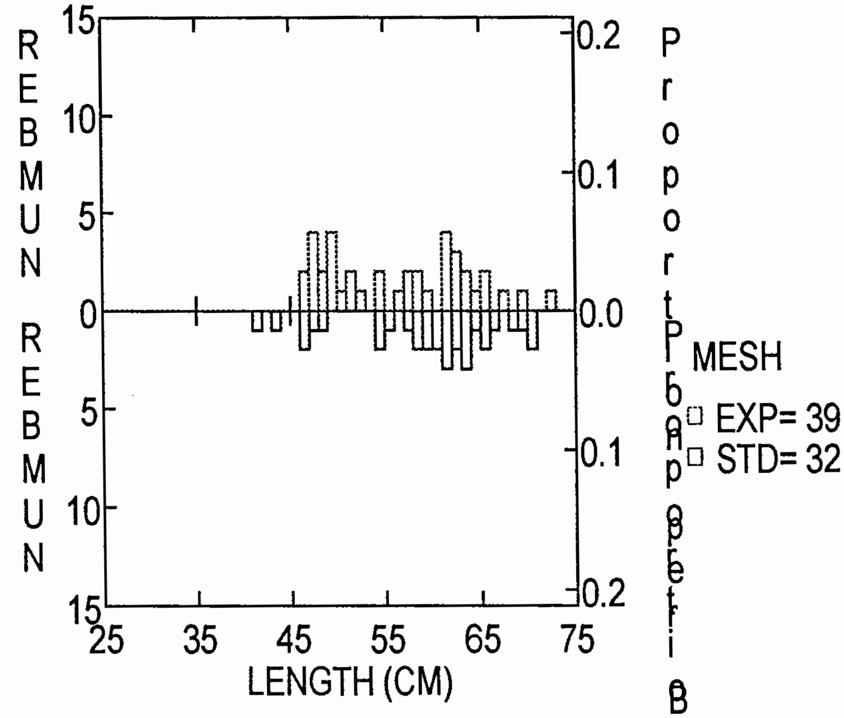
HADDOCK LFD IN CONTROL1 EXPERIMENT



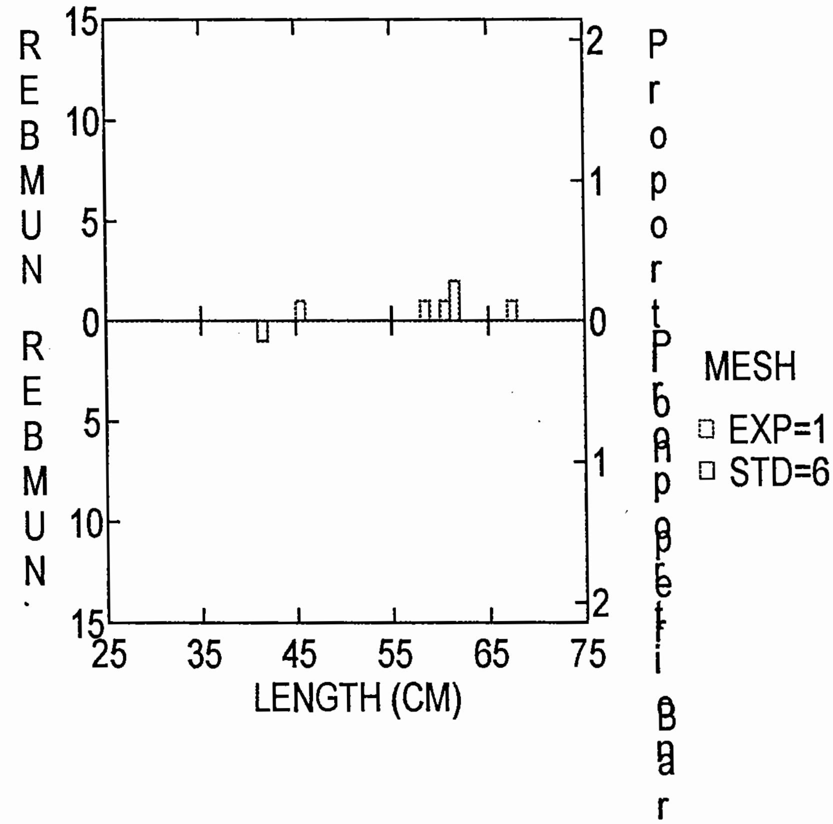
HADDOCK LFD IN 6.5" SQ1 EXPERIMENT



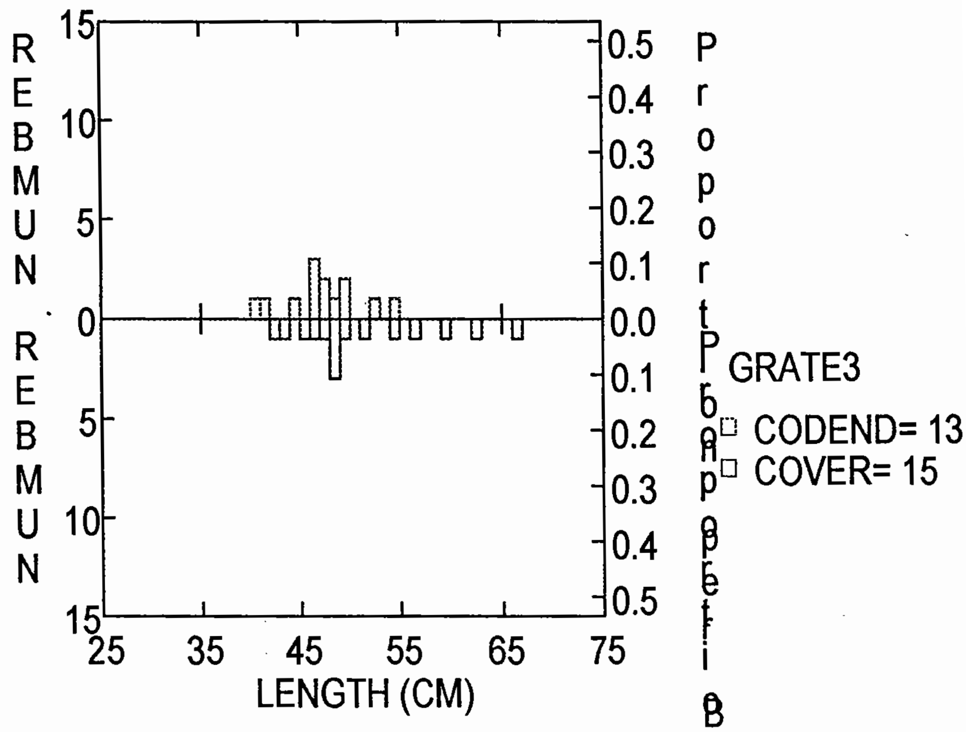
HADDOCK LFD IN 6" HEX EXPERIMENT



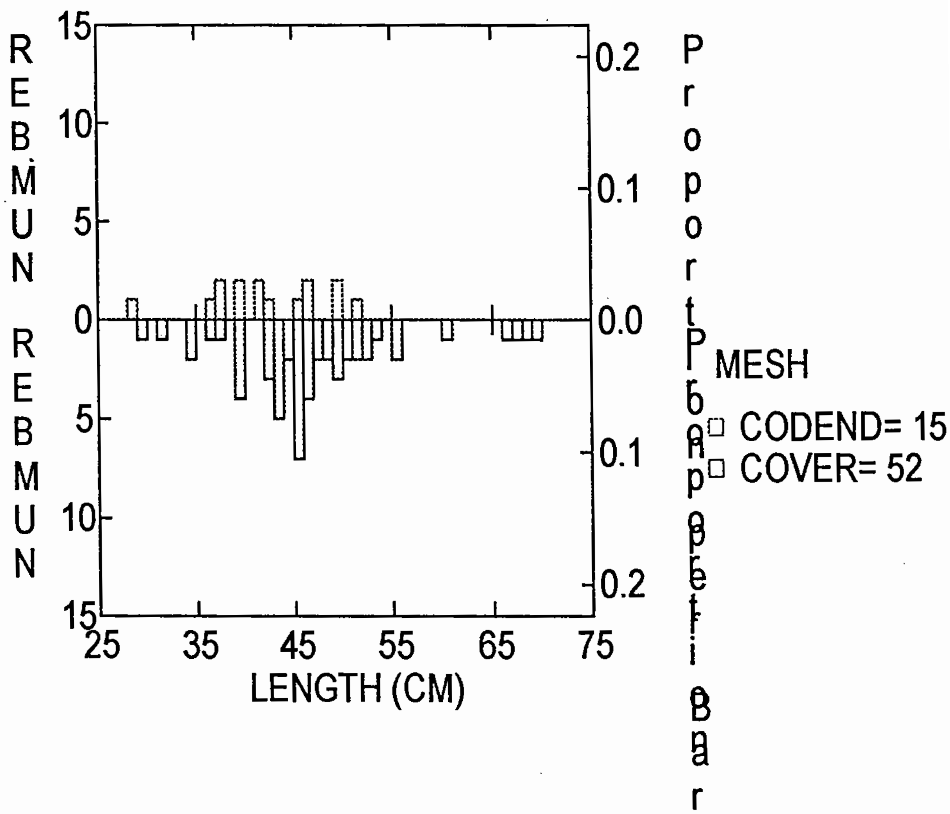
HADDOCK IN 6.5 HEX EXPERIMENT



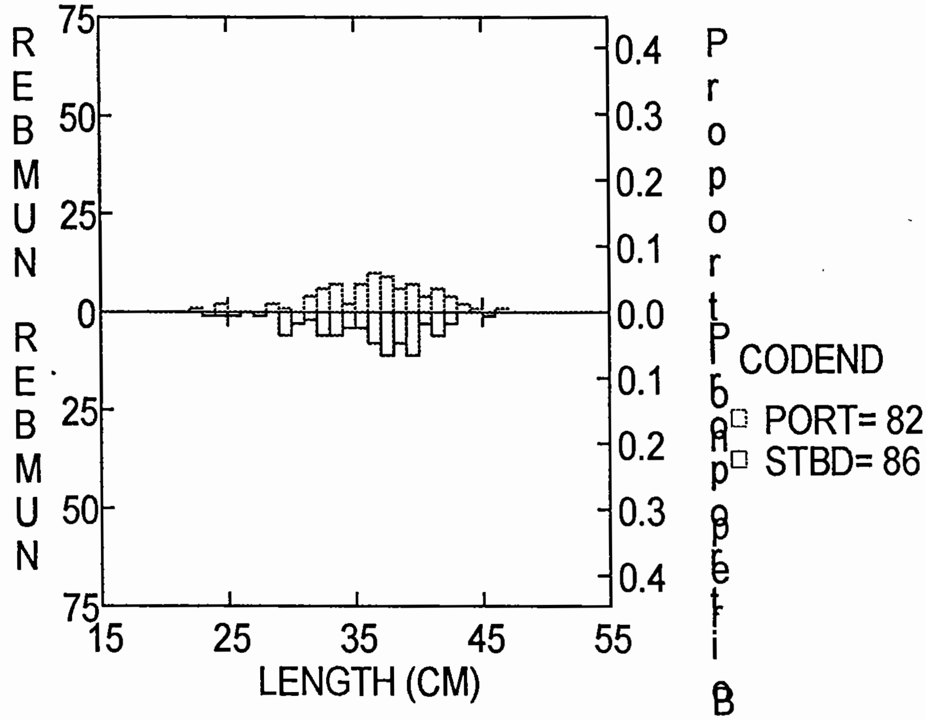
HADDOCK LFD IN 3" GRATE EXPERIMENT



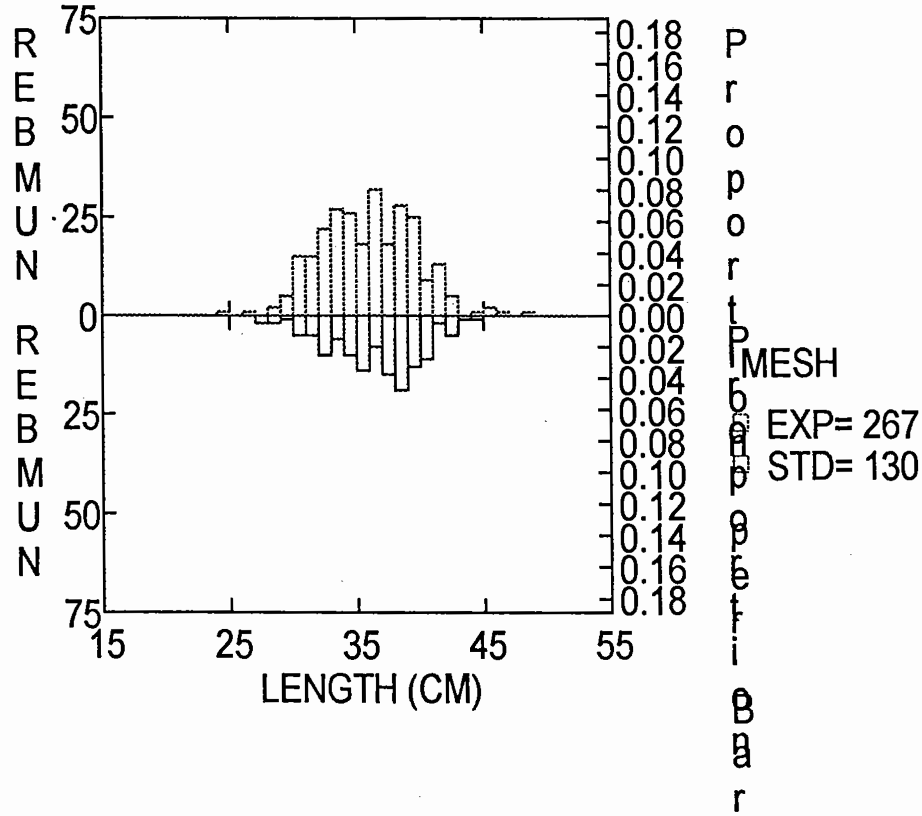
HADDOCK LFD IN 4" GRATE EXPERIMENT



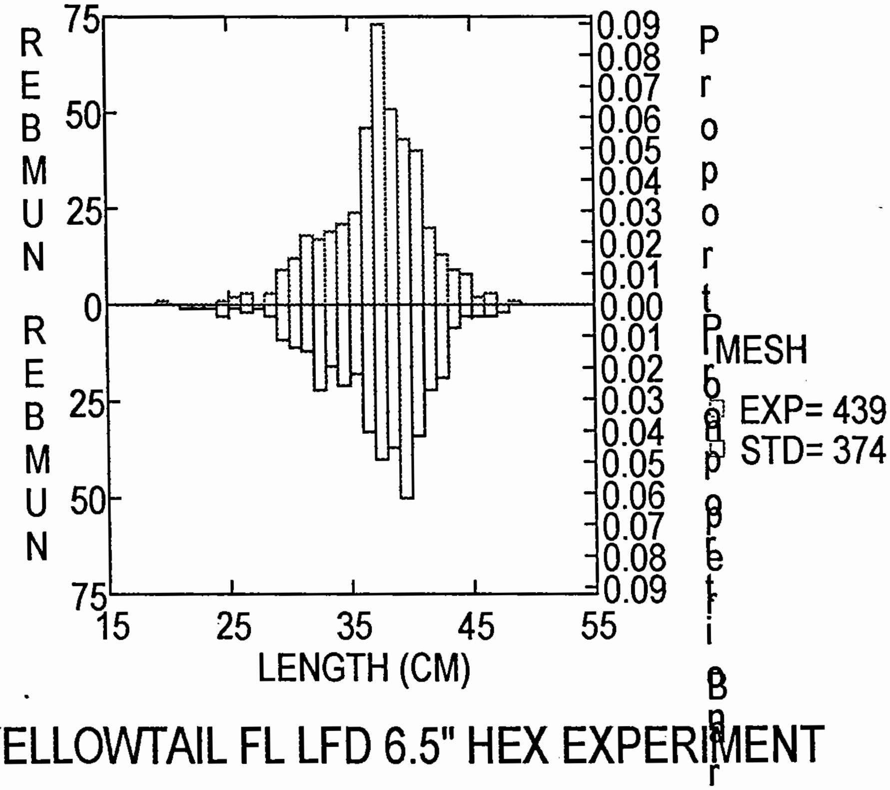
YELLOWTAIL FL LFD IN CONTROL1 EXPERIMENT



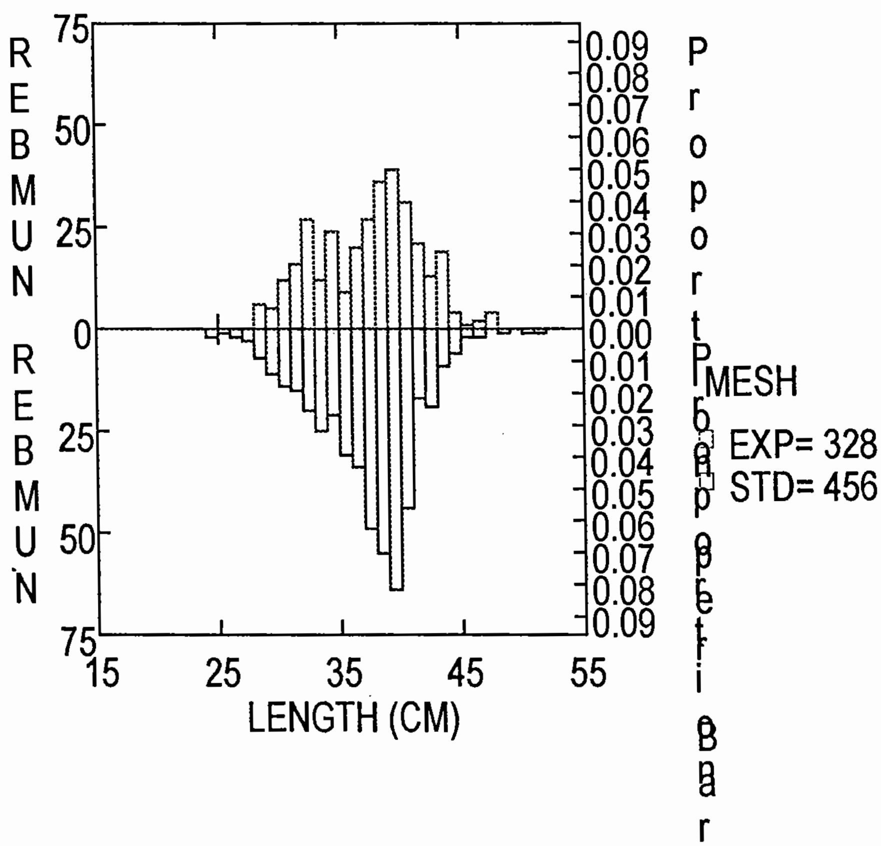
YELLOWTAIL FL LFD 6.5" SQ1 EXPERIMENT



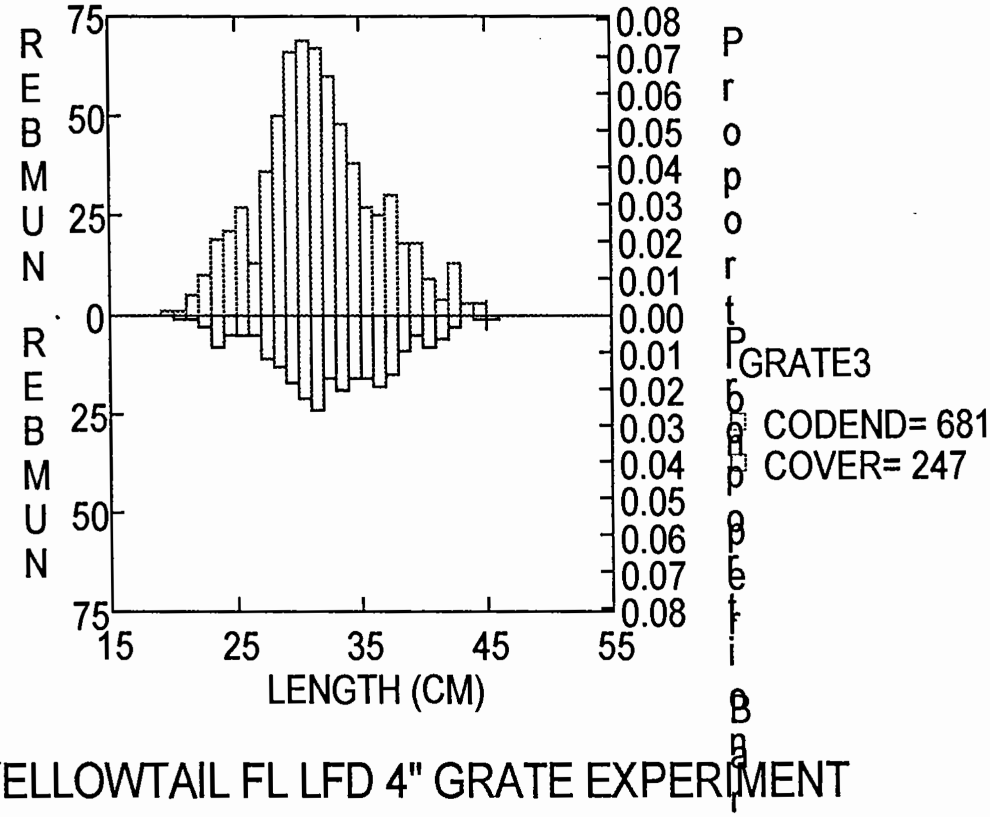
YELLOWTAIL FL LFD 6" HEX EXPERIMENT



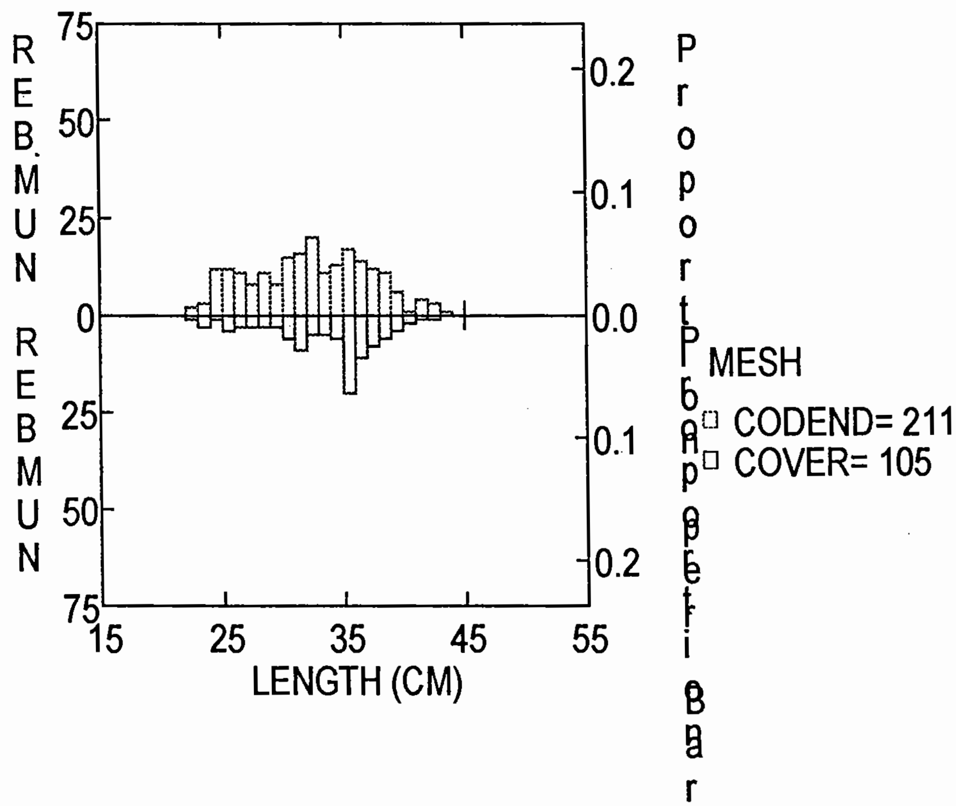
YELLOWTAIL FL LFD 6.5" HEX EXPERIMENT



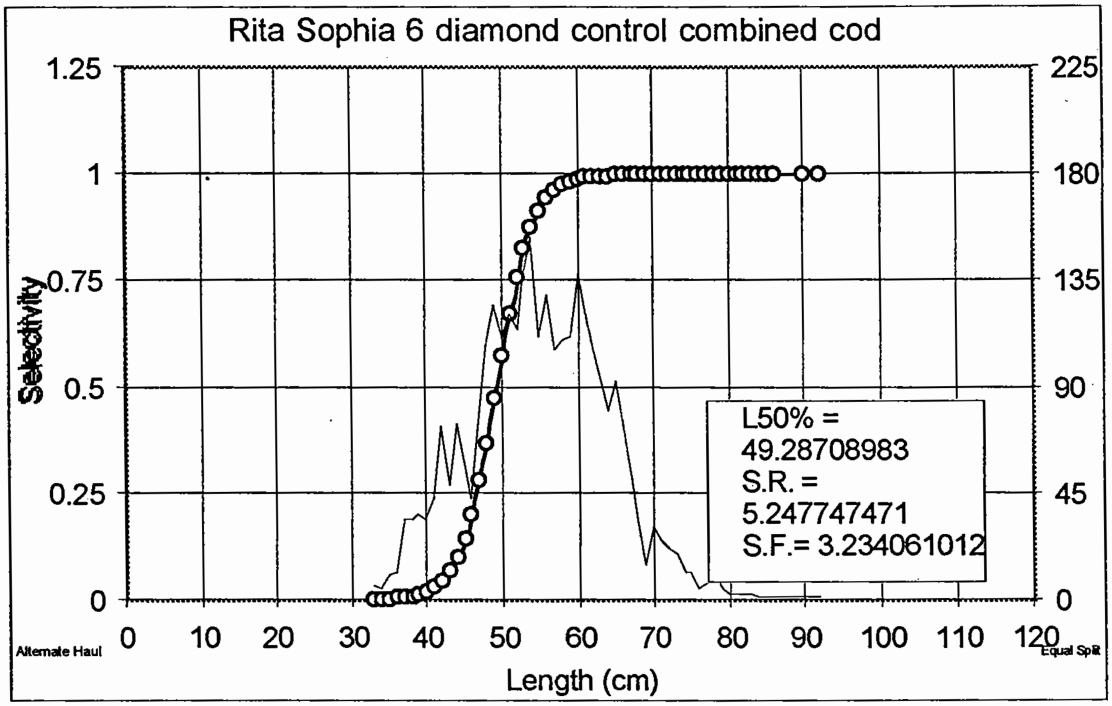
YELLOWTAIL FL LFD IN 3" GRATE EXPERIMENT

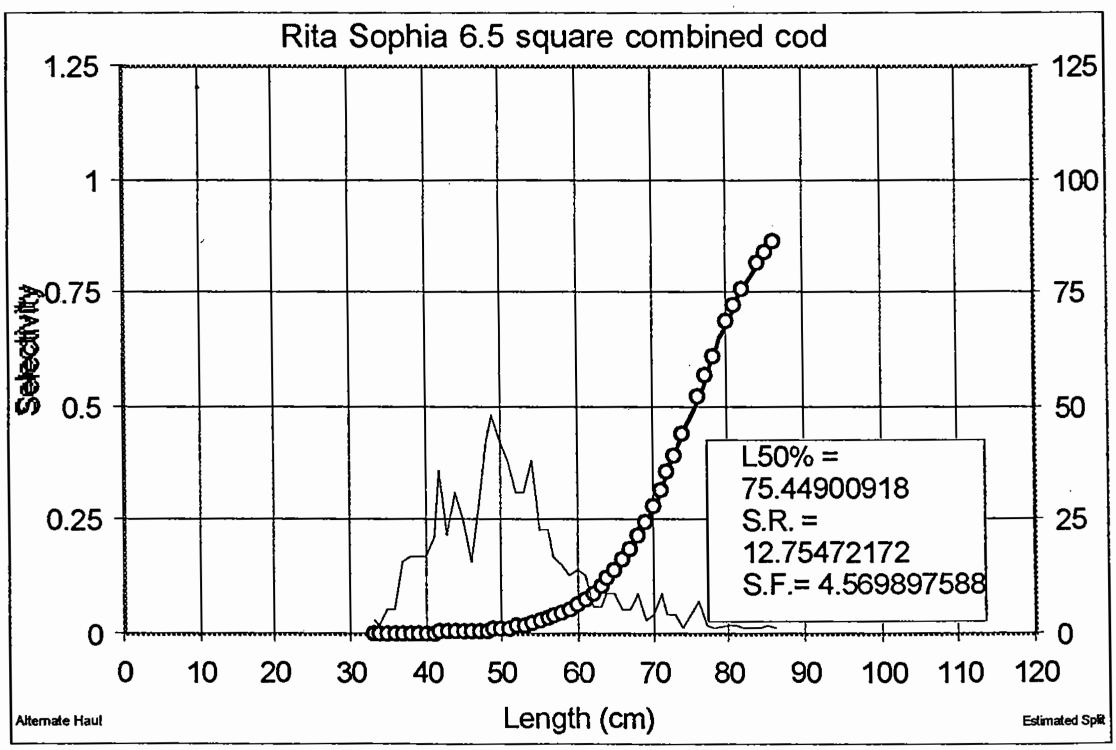


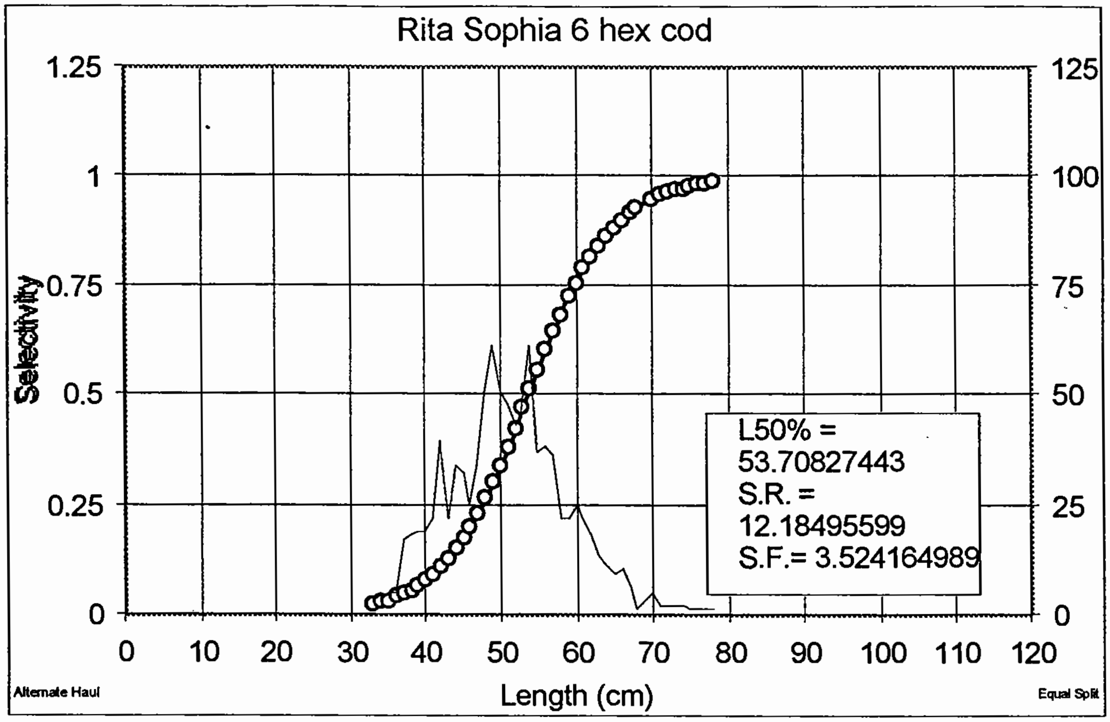
YELLOWTAIL FL LFD 4" GRATE EXPERIMENT



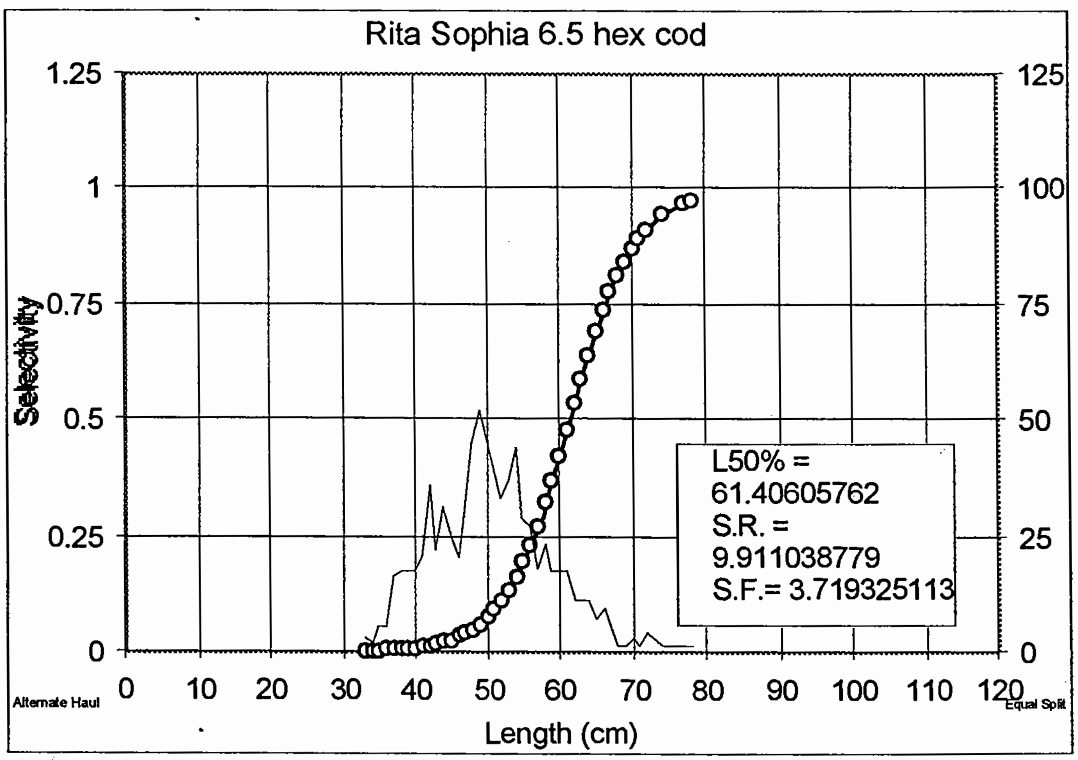
Appendix C. Length frequency distributions and selectivity curves by gear for cod and yellowtail flounders.



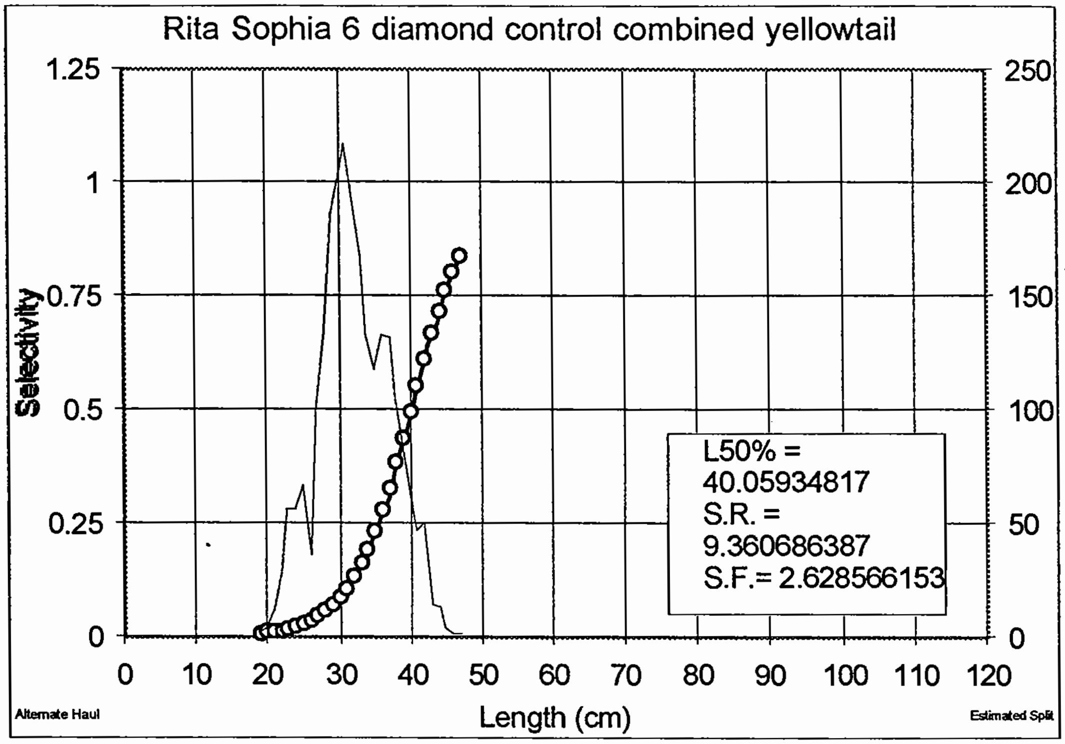




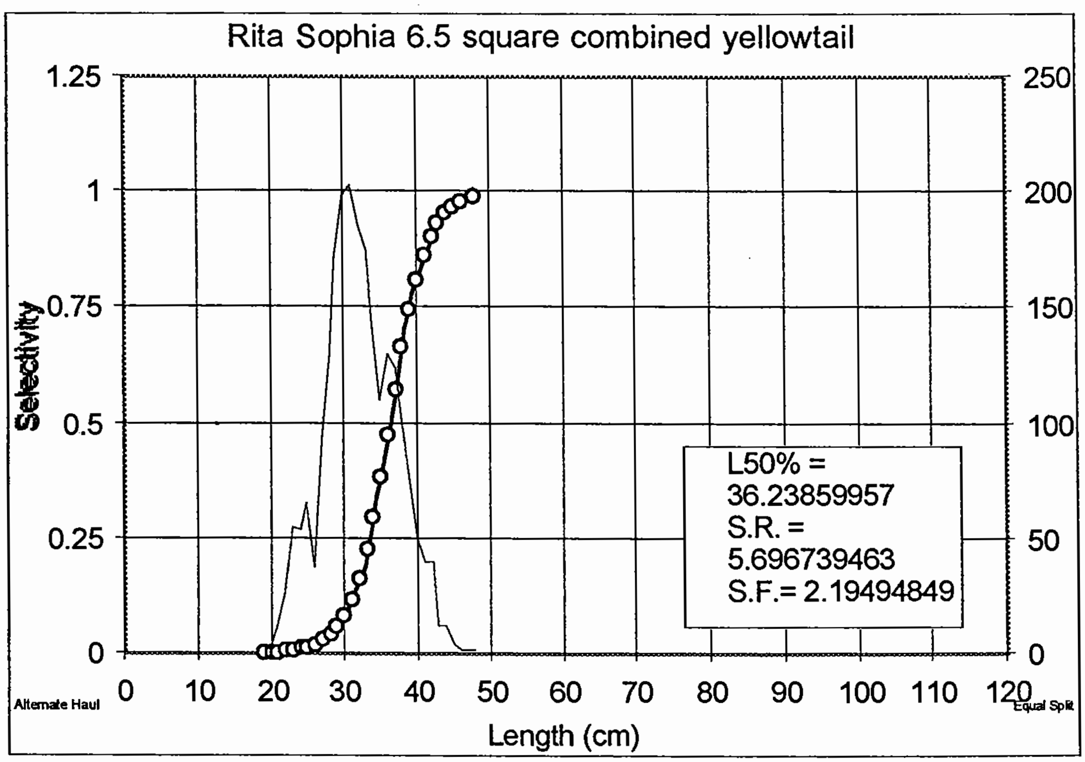
Rita Sophia 6 hex cod
Selectivity
1.25
1
0.75
0.5
0.25
0
125
100
75
50
25
0
0 10 20 30 40 50 60 70 80 90 100 110 120
Length (cm)
L50% =
53.70827443
S.R. =
12.18495599
S.F.= 3.524164989
Alternate Haul
Equal Split



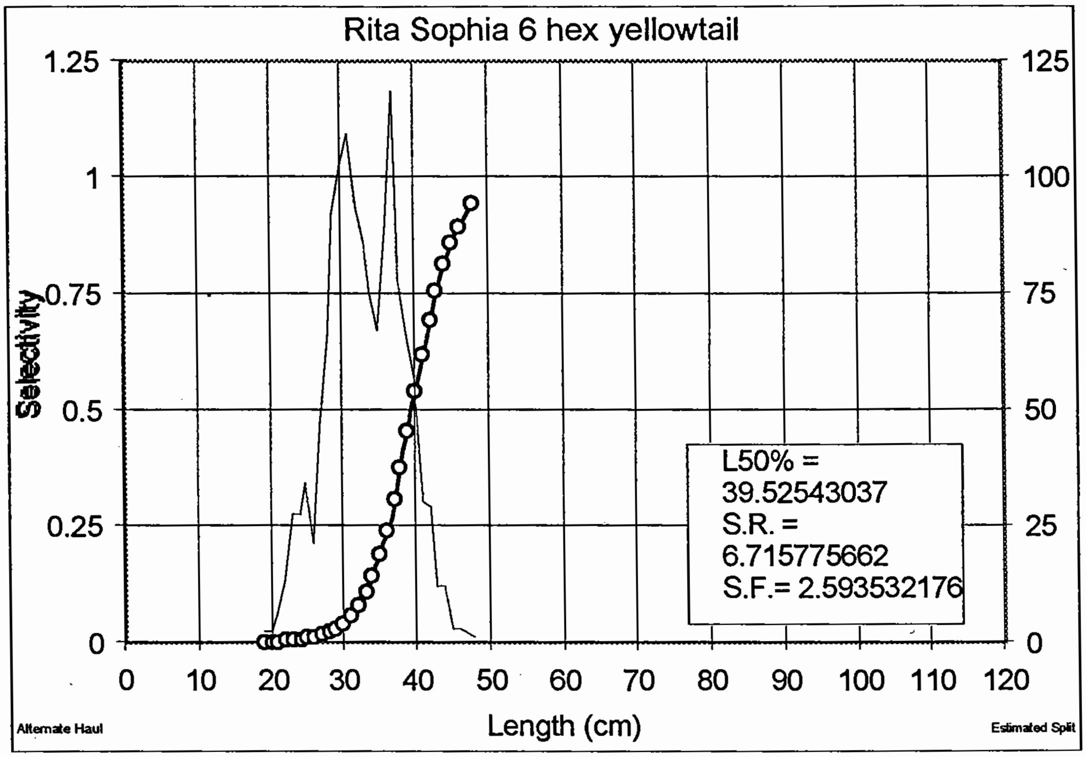
Rita Sophia 6.5 hex cod
Selectivity
1.25
1
0.75
0.5
0.25
0
125
100
75
50
25
0
0 10 20 30 40 50 60 70 80 90 100 110 120
Length (cm)
L50% =
61.40605762
S.R. =
9.911038779
S.F.= 3.719325113
Alternate Haul
Equal Split



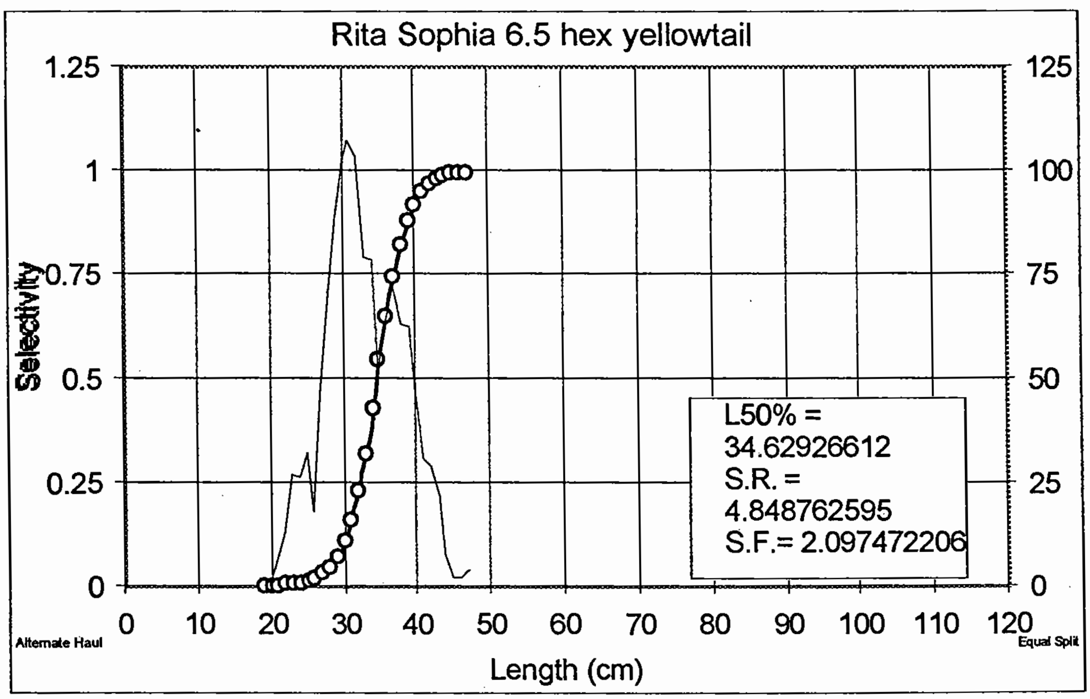
Rita Sophia 6 diamond control combined yellowtail
1.25
1
0.75
0.5
0.25
0
Selectivity
250
200
150
100
50
0
0 10 20 30 40 50 60 70 80 90 100 110 120
Length (cm)
L50% =
40.05934817
S.R. =
9.360686387
S.F.= 2.628566153
Alternate Haul
Estimated Split



Rita Sophia 6.5 square combined yellowtail
1.25
1
0.75
0.5
0.25
0
Selectivity
250
200
150
100
50
0
0 10 20 30 40 50 60 70 80 90 100 110 120
Length (cm)
L50% =
36.23859957
S.R. =
5.696739463
S.F.= 2.19494849
Alternate Haul
Equal Split

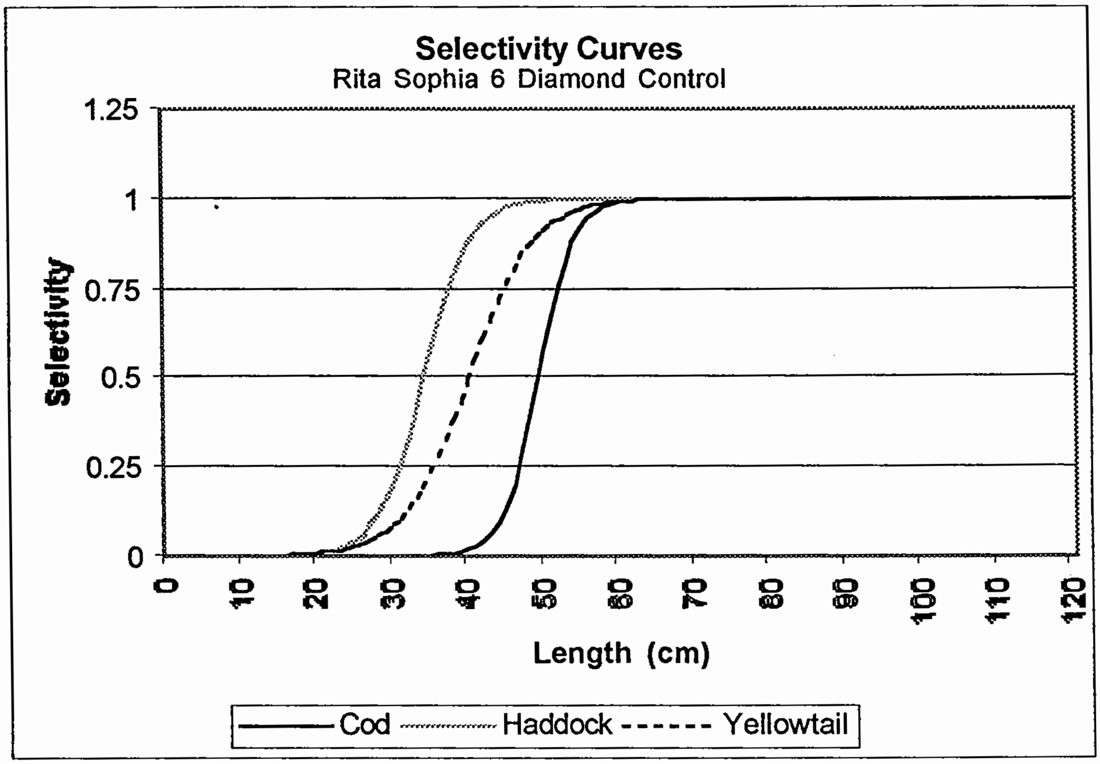


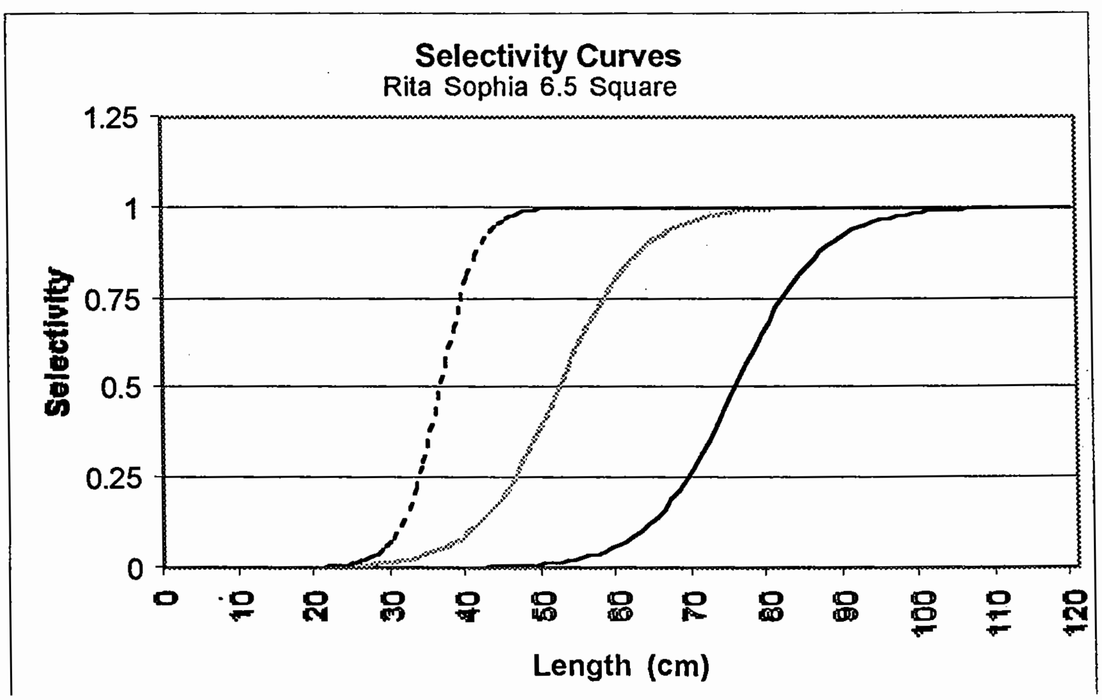
Rita Sophia 6 hex yellowtail
1.25
1
0.75
0.5
0.25
0
125
100
75
50
25
0
Selectivity
0
10
20
30
40
50
60
70
80
90
100
110
120
Length (cm)
L50% =
39.52543037
S.R. =
6.715775662
S.F.= 2.593532176
Alternate Haul
Estimated Split

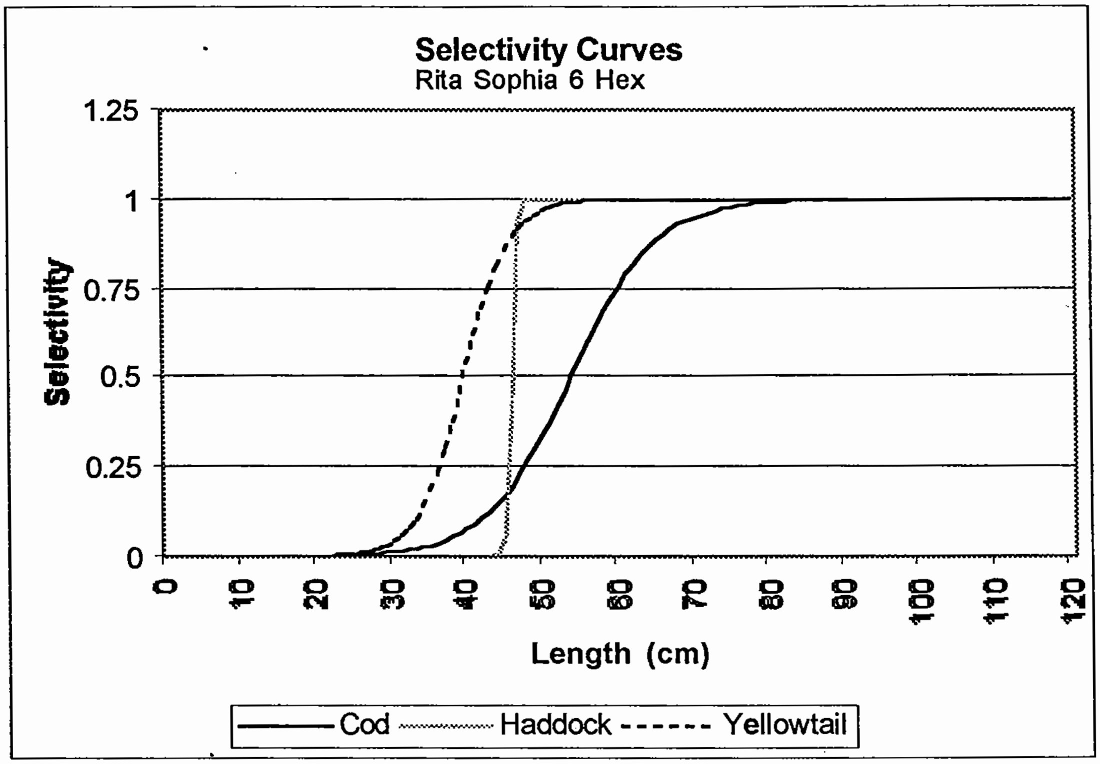


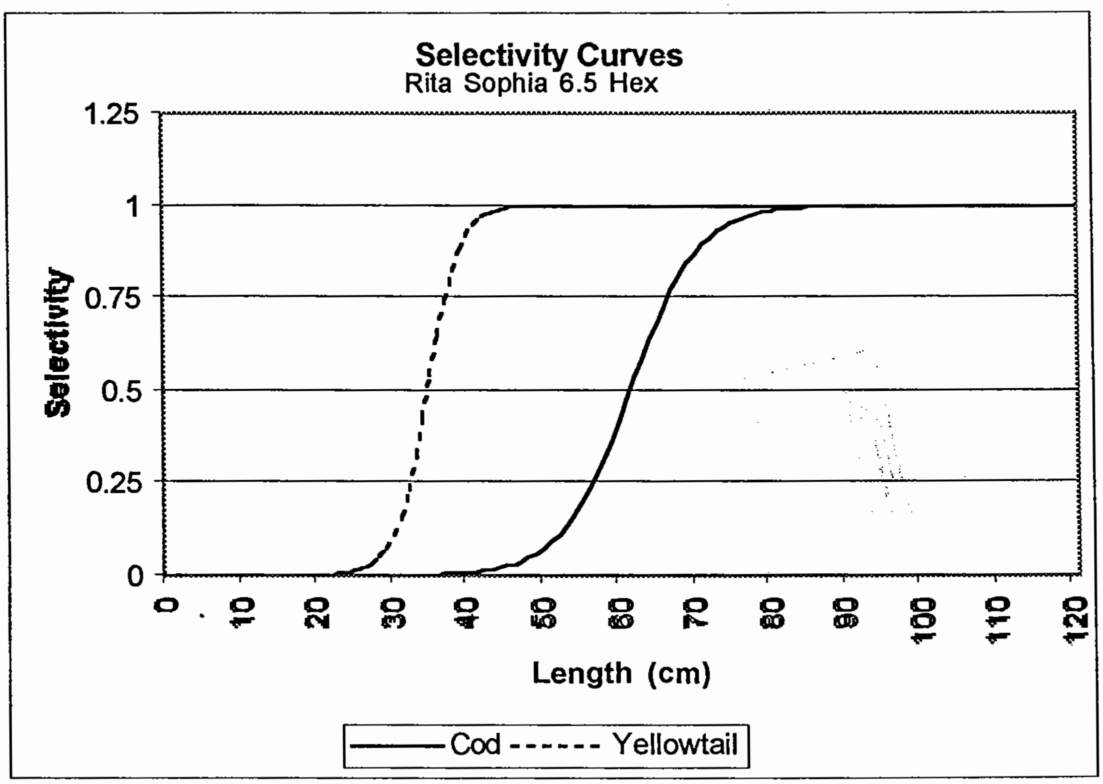
Rita Sophia 6.5 hex yellowtail
1.25
1
0.75
0.5
0.25
0
125
100
75
50
25
0
Selectivity
0
10
20
30
40
50
60
70
80
90
100
110
120
Length (cm)
L50% =
34.62926612
S.R. =
4.848762595
S.F.= 2.097472206
Alternate Haul
Equal Split

Appendix D. Selectivity Curves by species for each gear.






Selectivity Curves
Rita Sophia 6 Hex
Selectivity
1.25
1
0.75
0.5
0.25
0
0
10
20
30
40
50
60
70
80
90
100
110
120
Length (cm)
Cod
Haddock
Yellowtail


Selectivity Curves
Rita Sophia 6.5 Hex
Selectivity
1.25
1
0.75
0.5
0.25
0
0
10
20
30
40
50
60
70
80
90
100
110
120
Length (cm)
Cod
Yellowtail